BLOCKCHAIN AND PROPERTY IN 2018

AT THE END OF THE BEGINNING

J. MICHAEL GRAGLIA AND CHRISTOPHER MELLON

Before considering the evolution of blockchain for land governance, it is important to consider wider developments in the blockchain ecosystem of which it is a part. Many of the technical and legal obstacles highlighted in this paper, such as the lack of interoperability and legal recognition of digital signatures, are being addressed for other use cases. The widespread adoption of blockchain is not only a question of technical development, but of the degree to which society embraces the sort of decentralized governance models that it can orchestrate. Blockchain is unusual in that it is a social technology, designed to govern the behavior of groups of people through social and financial incentives. It is therefore inherently political in a way that few other technologies are. This quality has swept blockchain into the growing debate over reforming the power structures that govern the digital world.

It was the Russian interference in the 2016 U.S. presidential election that elevated this previously obscure issue to a prominent place in the public discourse. The fundamental problem that has been identified is that the consolidation of power in the hands of a few tech giants has become socially and politically dangerous. Proponents of this idea point to a variety of ills arising from the centralized control of data and of the attention economy in which it is generated, collected, and sold. These include the exploitation of social media marketing by political influence operations, the promulgation of extremist content, algorithmic bias,[1.] and the monetization of attention.[2.]

A few companies, notably Facebook and Google, effectively control the online marketplace of ideas. As a result, they find themselves responsible for, among other things, policing speech on their platforms. But despite having accumulated powers previously diffused amongst the media, government, and civil society, these platforms are privately governed. And as for-profit enterprises, their interests are aligned not with those of the public, but with those of the shareholders to whom they are accountable.

Moreover, the problem is inherently difficult to correct. The ubiquity of these platforms makes it hard for even the most socially-conscious users to "vote with

their feet" by choosing alternatives that better reflect their values. For many people, the cost of leaving Facebook is prohibitive, as they would have to leave behind the data that comprise their online social connections and identity. It is similarly difficult for regulators to address the problem, as increasing compliance costs could lock the dominant companies into a permanent hegemony. At a recent New America event, "Who's Afraid of Online Speech?" Sen. Amy Klobuchar and Rep. Ted Lieu discussed the difficulty of legislative solutions. As Rep. Lieu noted, the U.S. government could require social media platforms to review posts and ads for fake news and extremist content, but while Facebook and Google could bear the subsequent hiring costs, startups would be priced out of the market.[3.]

One clear solution would be to decentralize control of the information economy, beginning with open protocols for personal ownership of digital identities and user data. This would make personal data portable, allowing users to bring their data to the platforms of their choosing. More importantly, current advertising-based revenue models would be upended. Further decentralization of the Internet, including the Domain Name System and file storage, would have additional advantages, including increased privacy, censorship-resistance, and resilience against data breaches (e.g., the Equifax breach) and Distributed Denial of Service attacks.

Though the movement to decentralize the Internet has existed for some time—and has prominent advocates including Sir Tim Berners-Lee, inventor of the World Wide Web, Internet pioneer Vint Cerf,[4.] and the Mozilla Foundation—it has suffered from a lack of resources, both financial and technological. In the decade since its introduction, blockchain has emerged as the best candidate to solve these problems by attracting investment and enabling open,

ABOUT THE AUTHORS

Michael Graglia is the Director of the Future of Property Rights program at New America. Graglia comes from a career in international development and strategy that has seen him in finance at the Gates Foundation, program evaluation at BCG, developing a global tertiary education network at the World Bank Group, managing a national refugee program for the International Catholic Migration Commission in Zimbabwe, and teaching math in Peace Corps Namibia, where he founded a scholarship program to fund women's education. Graglia has an MBA from Columbia University, where he was a Bronfman Fellow, an MA in Southeast Asian studies from Johns Hopkins SAIS, where his studies were supported by the Paul & Daisy Soros Fellowship for New Americans. Graglia studied mathematics and computer science at Gonzaga University, S.J.

Christopher Mellon is a Policy Analyst with the Future of Property Rights program at New America. Previously, he was a researcher with New America's International Security program, where his work focused on international hostage-taking. Prior to New America, Mellon worked as an IT contractor for the U.S. Department of Defense. He is a graduate of St. John's College, Annapolis.

decentralized applications. As Steven Johnson wrote in a January 2018 *New York Times Magazine* article, "right now, the only real hope for a revival of the open-protocol ethos lies in the blockchain."[5]

Decentralizing the Internet would involve solving some of the most challenging prerequisites outlined in this paper, including digital identity. It would also require a great deal of investment in blockchain infrastructure and standards, the lack of which is commonly cited as the greatest obstacle to the creation of an Internet of Value. Furthermore, it would necessarily be accompanied by an attitude shift towards comfort and familiarity with decentralized governance structures.

It is not certain that the open, decentralized ethos will prevail.[6] The repeal of net neutrality protections may be taken as a sign that the current political climate does not favor a move away from corporate control. And in 2017, Google became the largest corporate lobbyist in the United States, "allocating more than $18 million to lobby Congress, federal agencies and the White House on issues such as immigration, tax reform, and antitrust. It also spent money to weigh in on an effort by lawmakers and regulators to regulate online advertising, which is at the core of Google's business, according to disclosures filed to the Senate Office of Public Records."[7] On the other hand, these trends are a powerful argument for accelerating the development of open protocols and decentralized applications.

Concern over the negative influence of the Internet giants is creating some pressure to change their business models. In February 2018, Europe's seventh-largest company, Unilever, announced that it would stop advertising on Facebook and Google if they did not take steps to become more socially -responsible.[8] In a speech at the IAB Annual Leadership Meeting in Palm Desert, California, Unilever CMO Keith Weed said, "it is acutely clear from the groundswell of consumer voices over recent months that people are becoming increasingly concerned about the impact of digital on wellbeing, on democracy—and on truth itself," and that "2018 is either the year of techlash, where the world turns on the tech giants—and we have seen some of this already—or the year of trust. The year where we collectively rebuild trust back in our systems and our society."[9]

This rhetoric accompanied the announcement that Unilever and IBM were partnering on "the first Blockchain solution for media buying,"[10] but its invocation of trust is still significant. It is true that the information economy is undergoing a crisis of trust. The question is whether trust will be restored by the tech giants reforming themselves to suit the demands of the current political climate, or if it will be created by the blockchain "trust machine."[11] If it is the latter, and it is decided that the digital world—in which our time, our money, and our social relationships are increasingly invested—must be governed in accordance with the sort of open and democratic values we insist upon in the non-virtual world, then the result will be an environment that is better prepared to accommodate the more radical scenarios described in this paper.

BLOCKCHAIN MAKES SENSE FOR REAL ESTATE

Driven primarily by private-sector investment, blockchain-based technologies are being developed to address a number of land and property related challenges. This paper examines how those technologies have been applied to land registries and real estate to date and considers how blockchain and registries may evolve going forward.[12]

High-friction transactions are hardwired into the structure of modern real estate markets. As a result, legacy infrastructure in the sector is slow, expensive, and brittle. For the median home sold in the United States, transaction costs can constitute up to 10% of the total sales price. Entire industries have emerged for the sole purpose of capitalizing on the inefficiencies of property transfers. The situation in less developed markets is often even more cumbersome.

Real estate transactions currently depend on a number of intermediaries, including brokers, government property databases, title companies, escrow companies, attorneys, inspectors, appraisers, and notaries. In the short term, sharing contracts and approvals in real time will reduce delays caused by mailing and delivery. Indeed, Goldman Sachs estimated that blockchain technologies could lead to an annual savings of $2-$4 billion in the real estate title insurance market alone.[13.] It would also eliminate the need for parties to reconcile documents, as all parties maintain an identical, immutable copy.

In addition, many time-consuming, expensive functions can be replaced with blockchain and smart contracts. Payments of rent, deposits, and fees could be automated. Escrow accounts could be redesigned around smart contracts and multisig wallets. The same infrastructure could be harnessed for other transactions that occasionally require resolution by a neutral party, such as disputes over rent deposits.

In the longer term, blockchain-based registries could allow peer-to-peer asset transfers, reducing transaction times from months or weeks to minutes. Transaction costs could come down from thousands of dollars per sale to a modest service fee.

The ease and security of transactions could also permit the efficient[14.] unbundling of property rights. A landowner could sell an easement to a neighbor quickly and cheaply. Investors could buy small shares in a rental property and receive their portion of the rent via an automated payment. This could allow individuals that cannot afford to buy entire parcels to invest relatively small amounts of money in real estate. This trend could have vast implications for financial inclusion, creating an international market for small real estate investments spread across multiple jurisdictions. Cross-border real estate investment is already projected to grow to over 50% of all real estate investment by 2020, and the emergence of blockchain could amplify this trend by introducing a class of real estate investors not limited by geography.[15.]

Because it is decentralized, fault tolerant, and virtually immutable, blockchain offers security and resilience advantages over traditional transaction and record-keeping systems. Records could be more resilient, as there would be no single, centralized repository vulnerable to destruction, as occurred in Haiti when "an untold number of title deeds and land registry records" were destroyed in the 2010 earthquake.[16.]

Fraud and error created by new transactions could also be reduced with an immutable ledger that tracks all transactions. This opportunity will have significant implications for national land registries and title insurance. The need for title insurance will be reduced, as proof of ownership can be established indelibly on the blockchain. The creation of more complete and reliable property records will provide a hugely valuable tool foranalysts, regulators, and land-management officials. Ultimately, we believe the ability to promote property rights formalization, registry modernization, and the collection and analysis of land-related data makes blockchain a disruptive technology for

land governance.

PREREQUISITES FOR BLOCKCHAIN INTEGRATION

As we wrote in 2017, there are a number of prerequisites that need to be in place before blockchain can be integrated into a registry.[17] These are:

- An identity solution
- Digitized records
- Multiple signature ("multisig") wallets
- A private or hybrid blockchain[18]
- Accurate data
- Connectivity and a tech-aware population
- A trained professional community

Below we briefly review these points with some updates from the initial writing. Those already familiar with this work are encouraged to turn to page 98, where we introduce the levels of integration we anticipate once these prerequisites are satisfied.

An identity solution

Registries tell us who has what rights to which asset, so knowing the "who" is critical. Land and buildings can be tied to a registry via maps, deeds, and surveys. Those documents can be connected to the chain via hashes, but how to validate identity?

At the moment, we are only aware of one blockchain-based national ID system, SecureKey in Canada, which launched in 2017.[19] Certainly, with Ukraine and Dubai's stated intentions of having their entire government "on chain," they may also be developing something.[20]

Decentralized blockchain-based identity platforms are being developed and may soon be viable options for registries. These include uPort, Civic, and, for those without personal devices, EverID. We do not suggest waiting for these systems; rather, a registry must leverage an existing digital identity system. In the Swedish pilot, for example, the large telecom company Telia provided the digital keys to verify identity.[21] In India, the Aadhaar identity platform is a logical choice.[22] Estonia also has a robust non-blockchain system.[23] In the U.S., one could imagine Login.gov, the Social Security Administration, or a state's DMV providing verification of identity to a registry.[24]

It is far better to use an existing, validated identity system than to create a new one just for a registry. This is both because identity management is a separate skill set and because using an established system or systems (if a federated identity verification approach is used) will result in higher quality information. Noel Taylor points out that, while "verification of identity is certainly a paramount requirement for the system to work, imposing a digital ID requirement on all who transact in the system will impede progress into developing countries if equality is not addressed."[25] We agree, but insist that digital identity must be solved first. SDG 16.9 aims to provide everyone with a legal identity by 2030.[26] We hope this goal is met because it will get us closer to more people enjoying increased tenure security.

Registries must be digitized

A hash "is a mathematical algorithm that maps data of arbitrary size to a bit string of a fixed size (a hash) and is designed to be a one-way function, that is, a function which is infeasible to invert."[27] One of the properties of hashing is collision resistance, where it is hard to find two inputs that produce the same hash.[28] Another quality of hashing is that even the slightest change to a digital file will produce a different hash—even file format has to be consistent.[29] By hashing a document and posting that hash to a public chain, it is

verifiably timestamped without being published. You cannot hash a paper document, though.[30] You can scan a document and hash the scan; any subsequent scan, however, would have a different hash, due to minute differences. Everyone would need the same copy in the same format in order for the hashes to agree. And it is hashing that empowers blockchains to mitigate against the alteration of records. So we recommend that a registry be completely digital before blockchain is integrated. Note that both Sweden and Georgia had fully digitized systems before incorporating blockchain.[31]

Multiple Signature Wallets

What happens if someone steals your key? What if you lose your key? What if someone holds a gun to your head and makes you sign over your house to them digitally without actually taking the key? The public-private encryption keys built into blockchain ensure that only those holding the associated keys can register or transfer a property. But if keys are lost or stolen, there must be recourse to recover the property associated with them. The issue of legal recourse is discussed in an upcoming prerequisite, but one clear mitigation, if not solution, is multiple signature ("multisig") wallets. These wallets require verification by a minimum number of keys, rather than a single key, before a transaction is completed. Instead of a seller simply pressing a "sell" button, a registry could require both a seller and a banker (or registrar) to sign off on the transaction. Multisig can be configured in any number of ways, requiring, for example, two of two, two of three, or three of five designated signers.

Some suggest a notary should be used as a second signer, but we disagree. There is no reason to shackle blockchain-based platforms to outdated systems already in decline.[32] Notaries are part of the system of middlemen and gatekeepers that is receding in the face of technical innovation. In the United States, for instance, notaries were historically used to vouch for identity, which modern identity systems may not require. Other stakeholders who have a vested interest in valid transactions—bankers and registrars, for instance—can act as second signers. Once identity is confirmed and all transactions are put in an immutable ledger, there is no need for a human notary in a blockchain-enabled process, much less a justification for the associated costs.

Those who excitedly envision direct, peer-to-peer exchanges of real estate and unbundled property rights may groan at the suggestion of multisig wallets, but for most homeowners that dream is more like a nightmare.[33] Despite the Parity multisig hacks, which were due to poor coding, we believe that multisig wallets will be secure and will prevent more problems than they will cause by the modest delays associated with their use.[34]

Use a private or hybrid blockchain

There is no universal format for blockchain-based registries, at least not yet, but we expect that they will all employ a private blockchain in some form. There are at least three good reasons for this:[35]

a. The judiciary and registrar must be able to adjust the ledger

On a public chain (BTC, ETH) there is only a record of the transactions by two willing parties identified by their public keys,[36] as well as any comments appended to their transaction. Generally, if fraudulent data was entered and discovered, the only recourse for correction is another transaction reversing the prior entry. If a court rules that one spouse gets the house,

but the other spouse does not want to transfer ownership, what happens? If someone loses their key or dies without communicating their key to another, how is ownership reallocated? What about expropriation of privately held lands for construction of public infrastructure? On a public chain, all of these questions are difficult to answer. But in a hybrid chain—where decisions are tracked on a private chain with hashes of key documents recorded on a public chain—they can be addressed by granting appropriate authorities to the registrar and judiciary, which is critical when managing real assets.[37] This could take the form of a special kind of multisig wallet where an ombudsman has a key allowing it to create reverse transactions on the private chain. Accenture has made a similar observation in the context of financial services.[38]

What happens if these authorities are abused? While this is a risk, one of the appeals of the blockchain is that it is a registry of all transactions. So while we advocate for exceptional authorities to issue new keys and create reversing (rather than overwriting) transactions where mandated by law, we do not suggest that this should be done in secret. Since all transactions will be recorded to the private chain and be visible to those with access, if configured appropriately, it will be far easier to identify and correct any abuse of authority.

b. Public chains cannot handle the volume of data involved

Registries contain deeds, titles, maps, plans, etc. All of these documents must be stored somewhere. Public blockchains cannot viably store such large amounts of data. Decentralized storage and transfer systems like IPFS, Swarm, Sia, Storj, and Maidsafe may solve the problem in the future, but they are still in the early stages of development and therefore are not ready to be entrusted with a property registry.[39] Registries can store the documents on a regular server and post the associated hashes to a public blockchain, but if a blockchain-based record of the actual data is desired, registries will need to use a private blockchain.

c. Anonymity is not an option

Registries need to know who is registering or transferring property records. Public blockchains allow anyone with the correct keys to broadcast valid transactions, regardless of who or what they are. A private blockchain is needed if registries want to ensure that only parties who have validated their identity to the satisfaction of the authorities are transacting. If nothing else, in jurisdictions with property tax, the tax authority may want more than a public key to hold liable for taxes.

Registries should be as accurate as possible

One of the merits of a blockchain is its ostensible immutability, so it is important to make sure that any existing data that is transferred onto the blockchain is accurate.[40] Jurisdictions looking to implement digital solutions are in one of three situations: they have a paper registry, a digital registry, or a registry that was destroyed.

All existing registries, whether digital or on paper, contain inaccuracies. Most causes of error are benign, but fraud and corruption always pose a risk. Simple administrative errors and property owners forgetting—or avoiding for tax optimization—to register changes also quickly cause outdated registries.

Ideally, the registry should be cleaned and current before it is put onto an immutable platform. The reality is that stopping to clean a registry risks creating disputes that would hinder a transition

for years. How bad is it if messy data is imported into a blockchain? Pulling a registry into a platform that allows for more transparency and lower transaction costs could expedite and facilitate clean up. This is particularly true in the case of a paper registry. It is often challenging to find errors in the registry or cadastre until it is digitized—with a poorly managed registry it is difficult to cross-check claims.

If a registry is in use, and functioning as the public record, it should be on the best available technology. If transitioning to a new technology surfaces erroneous or conflicting records, they can be addressed in a systematic manner. Records can be flagged, and a process giving all parties a voice can be initiated without delaying implementation. If, however, the registry is riddled with errors, resources may be better utilized to address those errors before incorporating blockchain into the registry.

Digital registries require connectivity and a tech aware population

Before a registry adopts a digital platform, it should consider the costs and support requirements. An initial response may be that these additional costs make a project unattractive, but the counterargument is that a new system should eliminate a number of prospective operating costs.

Blockchain software is complex, and the hardware requirements substantial. It is hard to imagine that most public agencies could take these responsibilities in-house. This is well-understood beyond the world of registries, hence the proliferation of Infrastructure and Software as a Service models (IaaS & SaaS).[41.] These models allow parties to purchase servers and software on a subscription basis instead of making substantial initial capital investments. We are seeing the same with Blockchain as a Service (BaaS),[42.] but this change in support model has budget implications, namely that while the upfront costs are avoided, they are replaced with recurring costs. The maintenance and troubleshooting costs, however, shift to the vendor, which must be able to guarantee a very low rate of failure. And while public proof-of-work blockchains have proven robust, secondary software like wallets, exchanges, and smart contracts can be soft targets for hackers. A professional level of quality assurance and quality control will therefore be required.

In jurisdictions where connectivity is limited or consumers are not comfortable with digital transactions, a blockchain registry may not be optimal. If the system is not already digitized, we suggest starting there and then revisiting blockchain later. Registry digitization alone is a challenge. The Jamaican registry had to retrain employees and transform its office culture to make their new digital system work, and moving to a blockchain-based system will likely face similar challenges.[43.]

Train the professional community that interacts with the registry

In the long run, some envision blockchain disintermediating many parties. In the near term, this is unlikely. Lawyers will still bring suits, judges will hear them, and real estate agents will offer value added services to clients who would prefer expert assistance. All of these parties will need to be trained on the new system in order for it to function properly. The importance of engaging the professional communities who will interact with the blockchain early on in the transition cannot be overlooked. Blockchain lawyers such as Andrew Hinkes remind us that lawyers will need to understand a number

Level	Name	Description	Example
0	No Integration	No use of blockchain	Most of the world
1	Blockchain Recording	Public blockchain used to record documents related to land transactions	Brazil, Georgia, Dubai
2	Smart Workflow	Blockchain used to record progress of a transaction	Sweden, Dubai Properties (Landstream)
3	Smart Escrow	Smart contracts used for escrowing payment	Propy
4	Blockchain Registry	Central database replaced with a permissioned blockchain	Dubai, Georgia
5	Disaggregated Rights	Various rights to a single parcel are disaggregated and managed via blockchain	No known example
6	Fractional Rights	Rights for a given parcel are fragmented and managed via blockchain	No known example
7	Peer-to-Peer Transactions	Rights are transacted without intermediaries on Level 4 system	No known example
8	Interoperability	Different blockchain registries merge	No known example

Table 1. Blockchain Property Registry Adoption Levels

Source: Future of Property Rights program, New America

of issues, including how to present records from the blockchain, how to interpret records, and how to harmonize evidence rules with output from the blockchain. To do any of those things, they will first need to be trained in the fundamental concepts, capabilities, and vocabulary of the blockchain. Even with a clear picture of the technical and structural requirements for a blockchain registry, a great deal of work will remain in the form of education and capacity-building.

FRAMEWORK FOR BLOCKCHAIN-REGISTRY ADOPTION

Once these prerequisites are satisfied, what does integration actually look like? How will it evolve? What does it mean to put a registry on the blockchain? There are different ways to integrate or apply blockchain to an immovable real property registry. Instead of enumerating each of these scenarios, we propose a progressive framework for how we see blockchain integrating with property registries over time. This progression is not envisioned due to limitations of the available technology—whether blockchain or a traditional database. Rather, it is the complexity and resulting inertia of existing processes, compounded by implementation costs, that makes a progressive approach most likely.

In January 2014, SAE International launched the standard J3016 Taxonomy and Definitions for Terms Related to On-

Road Motor Vehicle Automated Driving Systems.[44] According to *Car and Driver*, this was done to allow "automakers, suppliers, and policymakers to classify a system's sophistication," because, "no two automated-driving technologies are exactly alike."[45] A similar framework will benefit the developers and policymakers who are active in the space defined by the intersection of blockchain and land registries. The progression is not as clear in this case as it is with autonomous vehicles, and it is unlikely to proceed in as linear a fashion as the numbering may suggest. The levels represent increasing sophistication or complexity, as perceived by the authors.

We propose eight levels. The first four envision the two most commons forms of property transactions: sale and lease/rental. Starting with level five, blockchain is seen as facilitating the disaggregation of different types of rights as well as their fractionalization.

Level 0—No Integration

Here we include all non-blockchain systems, from informal land where there are no legal titles, to paper registries, to computerized registries that rely on a centralized database.

Level 1—Blockchain Recording

This is useful in situations where notaries are not available, or where trust in the existing system is limited.[46] Hashing is the process of taking any digital input—from a string of characters to a scan of a legal document like a deed or lease—and creating a unique output of fixed length.[47] The hash of a document is often referred to as the digital fingerprint, a unique identifier. By storing this hash on a public chain—such as BTC or ETH—one creates an independently verifiable record of the existence of the document, in a specific condition, exactly when it was recorded via timestamps and ownership (or at least association) via public and private keys. In other words, the document has been virtually notarized and publicly recorded.[48] Some existing intermediaries are concerned by this practice; a group of European surveyors and notaries documented some of these concerns at the World Bank in March 2017.[49] Despite their concerns, we believe that the use of public blockchains to record key documents is likely to continue. In jurisdictions where corruption is a concern, introducing a public record of hashes can make it significantly harder to falsify records. On the other end of the spectrum, in countries where there are strong open data movements (Sweden, Estonia) or high degrees of transparency (the Netherlands), a public document registry may also be welcomed.

Examples: Brazil (Ubitquity) and Georgia (Bitfury) are using the Bitcoin blockchain to notarize the sale of properties.[50] The Netherlands is also using blockchain for leases. The Dubai Land Authority has the most advanced use case we are aware of. Per the *Gulf News*, the Dubai Land Department:

> has created its blockchain system using a smart and secure database that records all real estate contracts, including lease registrations, and links them with the Dubai Electricity & Water Authority (Dewa), the telecommunications system, and various property related bills. Dubai's blockchain's secure, electronic real estate platform incorporates personal tenant databases, including Emirates Identity Cards and the validity of residency visas, and allows tenants to make payments electronically without the need to write

> cheques or print any papers. The entire process can be completed electronically within a few minutes at any time and from anywhere in the world, removing the need to visit any government entity.[51.]

Level 2—Smart Workflow

This is useful as a way to both speed up existing work processes and make them more transparent. Real estate development and transactions are often complex, involving numerous intermediaries and elaborate processes. By publishing the completion of each step of the transaction on a permissioned chain and making those events visible to other participants in the transaction, timelines can be compressed dramatically. Along with mid-transaction transparency, hand-offs between parties become easier since everyone is using the same workflow rather than integrating numerous existing systems, which often introduces errors.

In the case of a real estate transaction, the steps—bank-approved credit line, offer accepted, deposit received, contract signed, etc.—involve numerous entities who need to interact and be certain that each has done their part. Collaborating via a blockchain will allow them to collapse the timeline and realize significant efficiencies. Another benefit of this application is that more members of an ecosystem engage with blockchain and as a result may become more comfortable with the technology, building support for deeper levels of adoption.

In the case of real estate development, the documents required to develop a project—sales and purchase agreements, progress reports, and master plans—need to move back and forth between developers and approving agencies.[52.] Having a trustless blockchain that can track these documents and increase visibility to all parties will expedite the process and reduce confusion.

Examples: Sweden with ChromaWay are using the Bitcoin blockchain to notarize transaction documents.[53.] Australian banks Westpac and ANZ are working with IBM to use blockchain technology for commercial leases. Their white paper on the project is informative.[54.] For project development, Dubai Properties and ConsenSys have developed a proof of concept for a product called Landstream. It was presented at the Arab Land Conference in February 2018 and went into production in March 2018.[55.]

Level 3—Smart Escrow

Smart contracts replace escrow agents in level 3. An escrow is "a deposit of funds, a deed or other instrument by one party for the delivery to another party upon completion of a particular condition or event."[56.] When smart contracts were envisioned in 1995 by Nick Szabo, he defined them as "a set of promises, specified in digital form, including protocols within which the parties perform on these promises."[57.] So instead of buyers, sellers, and banks depositing deeds, down payments, and mortgage payments with a professional escrow firm, all of those things are digitized and entrusted to a small program that lives on a blockchain and transfers ownership when all conditions are satisfied.

Aside from the clear implications of replacing a set of professionals with code, level 3 blockchain integration is significant because, as Andrew Hinkes argues, the impact of blockchains on contract law may minimize litigation exposure as well.[58.] Hinkes points out that oracles—external data sources upon which smart contacts may rely—remain a vulnerability. Oracles are susceptible to fraud or manipulation and although many projects seek to address oracle information

sources, they have many moving parts where they can break, be faked, or be manipulated. Smart contracts open a Pandora's box of legal issues if they do not behave appropriately.

Example: Propy.com has used this approach to facilitate the purchase of an apartment in Ukraine by a buyer in California paying with Ether and PRO tokens.[59] A detailed walkthrough of the transaction has been published.[60]

Level 4—Blockchain Registry

In all the previous instances, we imagined that the property registries existed as independent, centralized databases, which are supplemented in some way by the blockchain: in level 1 as a time-stamped signature, in level 2 as a shared source of truth regarding a process, in level 3 as smart escrow. In level 4, we imagine that a private permissioned blockchain replaces the central database and stores the actual records.[61] A private blockchain would be used to store the data for reasons of security, cost, selective privacy, and efficiency. The recording function, however, would still be performed on a public blockchain. This is not to say that all information would be private. Selective information from all transactions could made visible to a large number of participants, reducing the likelihood of fraud or other undesirable behavior. These observers could also be given permission to suggest edits or updates to the data-set, creating a better-curated data set over time. This arrangement could include built-in incentives to reward useful contributions.

Examples: Dubai is doing exactly this for their real estate documents.[62] Georgia is in the process of implementing such a system.[63]

Level 5—Disaggregated Rights

From levels 1 through 4, the rights in question will be ownership and occupancy, but once a blockchain becomes the registry, other possibilities present themselves. In level 5, rights can be disaggregated and discretely managed via a blockchain. Various rights associated with a property would be freely negotiated, using a blockchain system to track those transactions. Examples of other rights include, but are not limited to air, water, subsurface, mineral, grazing, and easements.

Level 6—Fractional Rights

Fractional rights are when a specific right is shared or divided between multiple users. This is frequently brought up in discussions about blockchain and real estate, but it would be more difficult in practice without level 5 integration in place. Fractionalization of rights allows for numerous scenarios. In addition to rights of ownership or occupancy, rights to revenues resulting from different uses of the property could also be fractionalized and traded.

Fractional ownership in this context could be defined as multiple parties sharing the rights and responsibilities of owning a real asset (i.e., a house, a condominium, or a commercial building), much like multi-investor leases.

Fractional occupancy could mean a number of things, depending on whether the right is divided in terms of space, time, or both. Examples of fractional rights include rights to a room in a house, or a bed in a room, or a time slot for a bed in a room, or rights to occupy an apartment, water rights being shared by multiple companies, or other third parties sharing the water on a land with owners, etc.

Beyond dividing how a property is used, both the governance and investment aspects can be allocated via

blockchain. Buyers will purchase shares in an asset, which translate to a stream of payments, assuming the asset is leased (investment), and also provides certain rights or decision-making abilities (governance). This is technically possible without blockchain—see the Australian example of Brickx.com—but with blockchain, the costs of allocating, recording, and trading these rights would be considerably lower.[64] Therefore, we should expect various models for minting, trading, and discarding these shares. Blockchains may also facilitate the scaling of the Brickx.com model.

Example: ConsenSys has announced a project called Pangea (now Meridio), which will do what Brickx.com is doing via the Ethereum public chain.[65]

In the long term, this service may expand to allow fractional ownership of properties rather than shares of derived products.

Level 7—Peer-to-Peer Transactions

These exchanges can occur only after the adoption of a blockchain and the clarification of legal rights. Overall, until levels 1-6 materialize, it is difficult to envision genuine peer-to-peer transactions without the presence of intermediaries.

In the case of Brickx.com, the use of a blockchain to facilitate their model, instead of a centralized internal system, could offer a similar user experience but with faster clearing and lower fees. The real potential for this model becomes clear, however, when it is applied without an intermediary. For instance, if a homeowner desires capital, instead of securing a home equity line of credit (HELOC) from a bank, they could simply fractionalize the rights to rent their house and enter into a long-term lease with themselves. The homeowner could then offer a fraction of the right to rental payments to any willing buyer via a smart contract. They would then be obliged to make payments to the owner of those rights (interest) until they paid off the initial cost (principal). Said differently, a level 7 registry with fractional rights would allow for a DIY HELOC or a crowd-sourced, peer-to-peer mortgage. In both cases it remains to be seen how these fractionated rights will be treated by the courts when failure to meet an obligation triggers a conflict.

Level 8—Interoperability

This would be something of a Holy Grail—interoperability between multiple blockchain-enabled registries and levels of jurisdiction—whether it is Santa Clara and San Mateo counties, the Netherlands and Spain, or China and the U.S. It is important here to distinguish that we are not talking about level 3. Rather, level 8 would be an actual peer-to-peer transaction between two blockchain-enabled registries. From a technology perspective, this would require some standardization of what defines a property on a blockchain between registries and blockchain firms in order to have a unified definition for a physical space and its associated rights. The political and legal challenges to such transactions would be significant. The vision here entails the world's property being managed on a large hybrid blockchain that came together by virtue of its interoperability. Another scenario could involve someone creating a blockchain that is capable of managing all the property in the world.

BEYOND COLORED COINS

The higher levels of our integration framework also require an appropriate digital instrument for conveying ownership. One solution for public blockchains is to use colored coins, cryptocurrency

tokens marked with metadata linking them to off-chain assets. The transfer of colored coins can in theory be used to represent transfer of the assets associated with them, but some legal scholars have concerns. An analysis by Rod Thomas published in the *European Property Law Journal* identifies two major obstacles to trading property with colored coins in common law jurisdictions.[66.]

First, he argues that colored coins may be unable to convey ownership of a specific property because they are based on currencies, which are fungible. Thomas argues that incorporeal interests, like easements or rights-to-rent charges, could be transferred by coin, but property ownership should not. He argues further that there would be no adequate process for redressing loss of a specific asset like a house because if a transaction went wrong, damages could be claimed but ownership of the property could not be reassigned.

The second issue Thomas identifies is that "competing claims" and "off-chain interests" would need to be recorded in the colored coin in order for it to allow secure transactions, and the owner of the coin cannot be trusted to be the gatekeeper. An additional problem is that, depending on the implementation, colored coins may only store a very limited amount of data.

Some of the objections mentioned above are also mitigated by the use of private or hybrid chains with multisig wallets, which we argued in the prerequisites section were the best structure for blockchain registries. Similarly, given that the higher levels introduce some complexity, we believe it would be preferable to create a standardized, purpose-built digital instrument for representing and conveying property ownership on chain. Instead of colored coins, such a system might be a robust digital identity system that gave identities to humans, parcels, and buildings, and then used the blockchain and smart contracts to record the relationships between them.

WHAT IS THE FUTURE OF BLOCKCHAIN FOR REAL ESTATE?

There are a number of well-known technical and legal obstacles to overcome in order for blockchain to be widely adopted in the real estate and land sectors. These include the lack of standard protocols for interoperability and the fact that the dominant public chains may perish, for a variety of reasons, including regulation of the cryptocurrencies that power them. Transaction speeds must increase without compromising data security. If we foresee a world with numerous micro-transactions, there must be adequate throughput speed to maintain it. This will depend in part on consensus mechanisms. Proof of Work has been very successful in large public chains, but it is slow and energy intensive. Ethereum's Proof of Stake mechanism remains unproven. More U.S. states are moving to recognize smart contracts and blockchain records, but early bills are occasionally compromised by the inability of lawmakers to define those technologies with sufficient accuracy.

The difficulty of these challenges should not be understated, but none of them is insurmountable and the potential for blockchain to improve land administration has generated a great deal of interest. In this section we explore the impact of blockchain on five areas: title insurance, legal reform, financial inclusion, big data, and regulation. Each of these topics is too large to be explored in a single paper, so we have kept our remarks brief and focused only on key issues.

What does blockchain mean for title insurance?

Title insurance differs from other common forms of insurance in that it insures against past, rather than future, events. It can be expected, therefore, that if the historical property record can be made more reliable, risk will be diminished correspondingly.[67] This makes title plants a very natural blockchain use case.

A widely cited analysis published by Goldman Sachs in May 2016 concludes that the impact of blockchain on title insurance will be to make title plants more efficient, reducing the cost of premiums.[68] Moat of the cost of title insurance comes not from actuarial risk but from fixed personnel costs, which "represent nearly 75% of industry premiums."[69] Title insurance companies can reduce these costs by using blockchain to create thorough and accurate records databases, enabling more efficient title searches and reducing the number of defective titles they have to correct. Goldman estimates that total cost savings created by blockchain will result in 30% lower premiums for consumers. Interestingly, they project that this will bring premiums across the U.S. in line with those in the state of Iowa, which is unique in having a state-run title insurance monopoly.[70] While the Goldman report acknowledges that the use of blockchain will "clean" property registries over time, it does not envision a scenario in which title insurance becomes unnecessary.

The question of whether a sufficiently comprehensive and reliable registry—for example, a blockchain registry that had been in place for decades—could eventually remove the need for title insurance altogether is interesting. This seems unlikely to happen in the U.S. without significant legal reforms, because in most U.S. jurisdictions there are documents that affect security of title but do not have to be recorded. Furthermore, documents can contain defects because they are not reviewed and validated by a responsible party prior to recording. As long as off-chain information can impact security of title, professional intermediaries will be required to perform due diligence and mitigate against risk, which is a barrier to peer-to-peer transactions. Under these circumstances, disintermediation is not desirable for the transacting parties, who would assume the risk themselves. The situation is different in Torrens jurisdictions, where the registration of a certificate of title is guaranteed by the state as proof of ownership and title insurance is usually not required.

According to the American Land Title Association, the U.S. title insurance industry "generated $14.3 billion in title insurance premiums during 2016 compared to $13.2 billion during 2015."[71] While there is broad agreement that blockchain will make the operations of title insurers more efficient, it is not clear what impact that efficiency will have on competition in the industry. The market is currently dominated by a handful of underwriters, with the top five companies having a 75% combined market share in the third quarter of 2017.[72] Early adoption by a major player could lead to consolidation in the industry as it out-competes and acquires its rivals. Though it seems likely that early adoption will be by established companies migrating their existing title plants to the blockchain, it is also conceivable that private blockchain registry and workflow management providers could eventually compete with them. A company providing a parallel registry and managing document exchange between the buyer, seller, banks, registry, attorneys, escrow agent, notary, and brokers might accumulate enough records to start its own title plant over time and offer title insurance through its platform.

Is Torrens a better legal framework for a blockchain registry?

Most of the early blockchain-based real estate products have been oriented toward abstract title recording jurisdictions.[73] Complex tasks like recording transactions, managing workflows, and researching chain of title create obvious opportunities for cost savings from increased efficiency. It could therefore be argued that there is currently less of an economic incentive for Torrens jurisdictions to adopt blockchain. But the opposite may be true when it comes to the higher levels of blockchain integration proposed in our framework, which involve increased decentralization and liquidity of assets. At those later stages the security and simplicity of Torrens title may offer significant advantages.

In the short term, blockchain could reduce the time required to approve new title certificates in Torrens jurisdictions. In the long term, the adoption of blockchain registries could allow them to benefit from a greater degree of liquidity than could be achieved in abstract title jurisdictions, which include the majority of U.S. states and counties.

Greater security of title is the primary advantage of the Torrens system. A certificate of title is a government-backed guarantee of ownership, and it includes all encumbrances on the title document. This makes it easier to transfer ownership securely, and can greatly reduce the number of title disputes that burden the legal system, especially in places with unreliable or incomplete property records.[74] This security would be especially significant for peer-to-peer transactions. The indefeasibility of Torrens titles would allow buyers to know the validity of the seller's title and of their own claim once the transfer was registered, allowing digital title certificates to function more like bearer instruments.

When a legal claim is brought successfully against the holder of a Torrens title, the claimant receives monetary compensation from an indemnity fund and ownership of the property remains with the certificate holder.[75] This means that there must be a pool of money set aside for the purpose of compensation. In places like Australia, where the Torrens system originated, the government collects this money from title registration fees.[76] A blockchain-based registry could automate this function, collecting money for the compensation fund with transaction fees.

It is not clear that these potential advantages would be enough to drive adoption of the Torrens system in the U.S. It is used to a limited extent in a number of states, including Minnesota, Washington, and New York, but was never widely adopted after its introduction in the nineteenth century. This is largely because the expense of migrating a property in the U.S. to the Torrens system has been too great to justify. A sufficiently compelling justification may develop if property transactions become increasingly decentralized.

Because of the cost and complexity of converting properties to Torrens title, this transition could not be done all at once. A more reasonable approach would be to move properties over to a parallel, blockchain-based registry over time. This could be achieved through incentivizing property owners to make the transition voluntarily, for example, to gain access to an international market for fractionalized property or peer-to-peer sales to foreign investors. Alternatively, the transfer could be prompted by a triggering event specified by the registrar. The latter has been done in the United States before, if on a small scale. In Hennepin County, Minnesota, the registrar converts proper-

ties to Torrens when they are repossessed for tax liens.[77] For our purposes, the triggering event is less important than the effect, which would be to produce a gradual transition to Torrens titles on a blockchain registry.

The idea that Torrens titles could be transferred and registered more easily and securely on a blockchain-based system depends on the willingness and ability of the registrar to approve and register documents in a timely fashion. In their examination of the advantages and disadvantages of Torrens title in the United States, the authors of *The Earthen Vessel* point out that

> because the registrar's office is not particularly sensitive to market forces, the inherent delays of the time consuming review of the documents for legal sufficiency by the registrar's office can be an unacceptable burden for those engaged in transactions. On the other hand, for the registration of records system, where the examination of title is completed by private representatives of the parties to the transaction, market forces are a factor, and where necessary, the attorneys can complete the examination of title and the closing on a transaction, based upon the needs and expectations of the client, in a very short period of time.[78]

It should also be noted that jurisdictions may be reluctant to embrace the Torrens system because of the cost of assuming liability and maintaining the indemnity fund. But as is the case in the title insurance industry, this risk would be reduced by improving the quality of property records. We should also reiterate that the argument presented here in favor of Torrens title is predicated on the idea that more liquid property transfers will be a great enough economic incentive to justify the disruption and expense of legal reforms. There are a number of reasons why this might not come to pass. It is possible, for example, that the overwhelming majority of blockchain-based transactions will be of property-backed investments in which ownership is not transferred. The broader question raised is whether some jurisdictions will stand to benefit more than others based on the degree to which their land laws map onto the characteristics of blockchain.

Will blockchain and land drive financial inclusion?

We should begin by emphasizing that, as Aanchal Anand, Matthew McKibbin, and Frank Pichel wrote in 2016, blockchain registries do not become significant for land governance until after land rights have been formalized:

> Simply put, blockchain does not resolve the primary challenge of land administration faced in many emerging economies—how to bring citizens and properties into the formal system. Blockchain will not help to identify who has what right and to where. It will not resolve property rights disputes as properties are brought into the formal system. Most importantly it won't resolve the tedious and time consuming process of collecting, verifying and bringing data into the system in the first instance.[79]

This is an important point, and as we described earlier, there are other prerequisites to blockchain registry adoption in addition to the existence of formal records. We do see the potential, however, for commercially oriented real estate platforms to speed up the formalization process indirectly through the promise of

financial inclusion.[80] Low-transaction-cost, low-barrier-to-entry platforms for accessing international property markets offer a powerful incentive for both governments and private companies to invest in the creation of modern and reliable property registries. Real estate investment would be a major addition to the list of inclusion opportunities enabled by blockchain, which include remittance services, mobile money, and economic identity. A 2016 market overview by the technology services company Cognizant estimated the "revenue generated by banks by 2020 within emerging markets from unbanked populations" at $380 billion.[81] If blockchain-based real estate markets can help to activate dead capital in those markets, this number will be radically increased.

There are already several companies positioning themselves to bring blockchain-based real estate solutions to the developing world. The most ambitious of these ventures may be De Soto Inc., though little has been made public about the company. According to Overstock founder Patrick Byrne, a partner in the venture, their goal is to put titles in the developing world on blockchain in a format that will allow them to be used as collateral for loans, with the resulting capital being traded on a tokenized market called tZERO.[82] It is unclear whether this is practicable, but it does indicate that serious business interests in the developed world are aware of the opportunity formalization represents and see blockchain as a key enabling technology. Byrne has even considered selling Overstock, which has a total market capitalization of roughly $1.5 billion, to fund De Soto Inc., telling the *Financial Times,* that "one of the possibilities is I sell the business and we have all the capital we need."[83]

This presents an interesting counterpoint to the idea that blockchain registries should first be introduced in highly developed jurisdictions like Sweden. The argument for emerging countries being early adopters is twofold: first, addressing problems like corruption is a greater incentive for adoption than the desire to upgrade an already functional system; second, efficient access to foreign property markets is more significant for emerging economies than for developed ones. Inasmuch as corrupt jurisdictions can be expected to oppose increased transparency, it must be hoped that the promise of economic development will be the the stronger motivating force. It can also be argued that greenfield scenarios without legacy data that must be cleaned and uploaded will allow for faster and cheaper implementation. Moreover, in emerging markets even relatively slow public chains can make transactions faster, mitigating current throughput limitations.[84]

Will blockchain (finally) bring big data to land?

In a paper presented recently at the World Bank's Land and Poverty Conference, Pranab Ranjan Choudhury, Manoj Kumar Behera, Saumya Sharma, and Tajamul Haque remark that the

> production, availability and accessibility of reliable data and statistics are of fundamental importance in monitoring and in taking evidence-based decisions for good land governance. The demand for data as evidence is increasingly focused to monitor global and national developmental status and targets.[85]

In the long term we can envision the widespread adoption of blockchain registries leading to a revolution in the empirical study of land governance. In combination with a rich digital ID system

including usage and demographic information, blockchain registries would create an unprecedented tool for studying the impact of land policies, bringing land into the era of big data. The consolidation of local property and transaction records into larger-scale national or supranational registries would be particularly valuable.

At least one of the companies that aspires to eventually create a global registry, Propy, seems to be aware of the value of this data. Touting itself as a potential "Amazon for real estate," it is positioning itself as both an online shopping platform and a provider of market data and intelligence.[86] From a development and governance perspective, this raises data ownership and registry privatization concerns that go beyond the scope of this paper.

In an interview published on March 5, 2018, Hernando De Soto and Patrick Byrne revealed that their joint venture would seek to document the actual occupation of land around the world rather than recording formal titles, giving "everybody, including authorities, an idea of the volume, the enormous volume of people outside the legal system."[87] They have not revealed how they plan to accomplish this.

At this point we should step back and ask why blockchain is being touted as the answer to these problems instead of existing, proven, cheaper technologies. As Peter Rabley of Omidyar Network reminds us, the problem with land registries

> isn't that the technology isn't there—we already have a whole lot of enterprise solutions and database technologies to store the records. What we need is to accurately map the areas where people are living. In India, they used geospatial technology to uncover 500,000 inhabitants of a slum that previously nobody knew about. Once we've been able to identify where people are living that's the first step to ensuring that they have property rights.[88]

We believe that where blockchain promises to distinguish itself from legacy technologies is in its ability to coordinate the verification of data and transfer of value between large numbers of people without the need for trust. As we discussed in the preceding section, this allows blockchain not only to secure property records but also to provide a transaction layer connecting those records to financial services. Furthermore, it can be used to organize decentralized data collection, which, as we have argued elsewhere with respect to land surveying,[89] is a necessity, given the vast amount of data that must be collected for large-scale formalization. In this domain, blockchain can contribute by tracking digital supply chains, providing financial incentives for data collection and validation. Land Layby is testing a token-incentivized private registry in Ghana that "rewards users for adding correct entries to the blockchain and penalizes them for erroneous ones."[90] The FOAM Protocol adds an open source geospatial layer to the Ethereum blockchain and incorporates economic incentives to drive the creation of crowdsourced maps. According to FOAM's founders, this will "allow any coordinate to be turned into a blockchain wallet that can hold a balance and be tagged with crowdsourced data."[91] In combination with other tools, like new earth observation technologies and digital ID, blockchain can become a core technology for property rights formalization.

How will blockchain for land be regulated?

In the foreword to this paper, we discussed how concerns over the social impact of the Internet could help create norms favorable to the adoption of decentralized technologies like blockchain. But there are countervailing forces that we believe will lead regulators to limit the decentralization of financial infrastructure. This would impact all assets traded with this infrastructure, though the impact on real property would depend on the degree to which blockchain increases liquidity.

A fully decentralized financial system would have troubling economic and security implications. For the West, and especially the United States, influence over the international financial system is an essential diplomatic and law enforcement tool, which can be used to sanction state rivals and disrupt the financing of hostile nonstate actors, most importantly terrorist groups.[92.] The fear that blockchain could undermine this status quo was first raised by the advent of cryptocurrencies, which bear mentioning here before addressing other blockchain-based financial applications.

The U.S. government's assessment of the terrorist financing and money laundering threat from cryptocurrencies is still evolving. A House bill was introduced in January 2018 "to establish an Independent Financial Technology Task Force, to provide rewards for information leading to convictions related to terrorist use of digital currencies, [and] to establish a FinTech Leadership in Innovation Fund to encourage the development of tools and programs to combat terrorist and illicit use of digital currencies."[93.] However, recent assessments by the EU and the UK treasury have concluded that the threat of terrorist groups financing themselves via cryptocurrencies is not yet a serious one.[94.] The June 2017 EU report, in particular, noted that terrorists still prefer fiat over digital currency.[95. 96.] There are at least two good reasons that cryptocurrency has not been treated as a major threat. First, the dominant crypto blockchains are only pseudonymous; there are tools that can reliably reveal the identities behind the public keys of malicious actors.[97.] Second, the pool of funds cryptocurrencies represent is miniscule compared to the larger economy.[98.] If or when large amounts of land are tokenized, this may cease to be the case.

A more significant threat to the current international order would be the creation of a decentralized value transfer system that would allow states to avoid international sanctions.[99.] It is no accident that countries like Russia and Venezuela have been quick to demonstrate interest in state cryptocurrencies.[100.] Venezuela has been a particularly dramatic example. During the ongoing economic crisis, Venezuelan citizens have turned to Bitcoin to escape hyperinflation, while the government has created an oil-backed cryptocurrency in an effort to circumvent U.S. sanctions.[101.]

The economic incentives of increased efficiency and international liquidity are certainly great enough to ensure the continued development of blockchain-based value transfer systems, but these systems can be expected to combine principles of decentralized exchange with traditional know-your-customer and anti-money-laundering features. A February 2018 report from the Council on Foreign Relations notes that "many of the largest U.S.-based [cryptocurrency] exchanges, including Coinbase and Gemini" already comply with these requirements, making it "challenging for criminal groups to convert their cryptocurrency into hard currency."[102.] It is also likely that multisignature wallets will be increasingly utilized,[103.] as we have suggested is appropri-

ate for land registries.

With respect to real property, states will retain the power to regulate and tax land transactions, allowing elected officials to be responsive to the constituents who inhabit the land in question. Taxes may increase transaction costs, but these will be offset by efficiencies from disintermediation. The ability to regulate local land markets is needed to mitigate against unintended consequences, such as asset prices skyrocketing in response to external capital flows. High degrees of liquidity and unrestricted property investment–facilitated by a blockchain-enabled registry—could drive up housing costs in areas favored by international investors. Foreign property investment from China has created this dynamic in Australia. In 2015, legislation was introduced to limit such investment after middle-class Australians "complained about being priced out of the housing market" by wealthy Chinese investors.[104.]

The need to retain sovereign control of property markets is one of the main reasons we argue for hybrid chains in the prerequisites. Governments must regulate the economy and enforce the law. Further, as blockchains become integrated into registries at higher levels, national laws, taxes, fees, and regulations will have to be integrated into smart contracts.

Acknowledgments

The authors thank Sade Bruce, Tim Robustelli, and Ethan Walker for their contributions to this paper.

1. Will Knight, "Biased Algorithms Are Everywhere, and No One Seems to Care," MIT Technology Review, July 12, 2017, https://www.technologyreview.com/s/608248/biased-algorithms-are-everywhere-and-no-one-seems-to-care/, accessed March 5, 2018.

2. Center for Humane Technology, "The Problem," HumaneTech.com, http://humanetech.com/problem/, accessed February 27, 2018.

3. "Who's Afraid of Online Speech?" YouTube video, 2:12:30, posted by New America, January 30, 2018, https://www.youtube.com/watch?v=q9FlATmYVcs.

4. Klint Finley, "Tim Berners-Lee, Inventor of the Web, Plots a Radical Overhaul of His Creation," Wired.com, April 4, 2017, https://www.wired.com/2017/04/tim-berners-lee-inventor-web-plots-radical-overhaul-creation/, accessed February 25, 2018; Klint Finley, "The Inventors of the Internet Are Try to Build A Truly Permanent Web," Wired.com, June 20, 2016, https://www.wired.com/2016/06/inventors-internet-trying-build-truly-permanent-web/, accessed February 27, 2018.

5. Steven Johnson, "Beyond the Bitcoin Bubble," New York Times, January 16, 2018, https://www.nytimes.com/2018/01/16/magazine/beyond-the-bitcoin-bubble.html?smid=tw-share.

6. Hamza Shaban, "Google for the first time outspent every other company to influence Washington in 2017," Washington Post, January 23, 2018.

7. Ibid.

8. "The parable of St Paul," Economist, August 31, 2017, https://www.economist.com/news/business/21727908-unilever-worlds-biggest-experiment-corporate-do-gooding-parable-st-paul.

9. "Unilever will not invest in online platforms that create division," press release, February 2, 2018, on Unilever website, https://www.unilever.com/news/Press-releases/2018/unilever-will-not-invest-in-online-platforms-that-create-division.html, accessed on February 15, 2018.

10. Keith Weed and Babs Rangaiah, "How Blockchain is Bringing Trust to Digital Ad Buys," IBM, February 14, 2018, https://www.ibm.com/blogs/think/2018/02/45885/, accessed March 5, 2018.

11. "The Trust Machine: The promise of the blockchain," Economist, October 31, 2015.

https://www.economist.com/news/leaders/21677198-technology-behind-bitcoin-could-transform-how-economy-works-trust-machine, accessed March 1, 2018.

[12.] Blockchain is a type of Distributed Ledger Technology (DLT). The World Bank defines DLT as, "a novel and fast-evolving approach to recording and sharing data across multiple data stores (or ledgers). This technology allows for transactions and data to be recorded, shared, and synchronized across a distributed network of different network participants" (See World Bank, "FinTech Note No. 1, Distributed Ledger Technology (DLT) and Blockchain," IV). While not all distributed ledgers employ blockchain technology, this paper refers almost exclusively to the blockchain model of DLT. Note also that there is no single, rigorous definition of blockchain. For more on this subject see Adrianne Jeffries, "'Blockchain' Is Meaningless," Verge, Mar 7, 2018, https://www.theverge.com/2018/3/7/17091766/blockchain-bitcoin-ethereum-cryptocurrency-meaning

[13.] "Profiles in Innovation: Blockchain—Putting Theory Into Practice," Goldman Sachs Group, May 2016, 7.

[14.] There is an important distinction to be made between the two kinds of efficiency that blockchain can create. The first, which underlies most of the current real estate applications, comes from simplifying processes and removing intermediaries. Examples of this sort of efficiency include using using public chains to timestamp documents and eliminating the need for reconciliation of records through shared ledgers. The second kind of efficiency, which remains unproven, is in facilitating secure, high-speed, low-cost transactions at scale.

[15.] Maria Angelova, "Real Estate cross-border transactions," Propy Inc., 2016, 5.

[16.] Anastasia Moloney, "Unclear land rights hinder Haiti's reconstruction," ReliefWeb, July 5, 2010, https://reliefweb.int/report/haiti/unclear-land-rights-hinder-haitis-reconstruction.

[17.] Michael Graglia, Christopher Mellon, and Evan Akin, "Prerequisites for Incorporating Blockchain into a Registry," FPR Blog (blog), New America, July 31, 2017, www.newamerica.org/international-security/future-property-rights/blog/prerequisites-incorporating-blockchain-registry/, accessed July 30, 2017.

[18.] The initial four prerequisites are specifically technical in character.

[19.] "IBM and SecureKey Technologies to Deliver Blockchain-Based Digital Identity Network for Consumers," press release, March 20, 2017, on SecureKey website, securekey.com/press-releases/ibm-securekey-technologies-deliver-blockchain-based-digital-identity-network-consumers/, accessed July 30, 2017.

[20.] Gertrude Chavez-Dreyfuss, "Ukraine launches big blockchain deal with tech firm Bitfury," Reuters, April 13, 2017, www.reuters.com/article/us-ukraine-bitfury-blockchain/ukraine-launches-big-blockchain-deal-with-tech-firm-bitfury-idUSKBN17F0N2, accessed July 30, 2017; Nikhil Lohade, "Dubai Aims to Be a City Built on Blockchain," Wall Street Journal, April 24, 2017, www.wsj.com/articles/dubai-aims-to-be-a-city-built-on-blockchain-1493086080, accessed July 30, 2017.

[21.] Lantmäteriet et al., "The Land Registry in the blockchain - testbed," Chromaway, March 2017, chromaway.com/papers/Blockchain_Landregistry_Report_2017.pdf, accessed July 30, 2017.

[22.] Government of India, Unique Identification Authority of India, About Aadhaar, 2016, uidai.gov.in/your-aadhaar/about-aadhaar.html.

[23.] Dave Birch, "Estonia, fake news and digital identity", Tomorrow's Transactions (blog), Chyp, March 20, 2017, accessed July 30, 2017.

[24.] U.S. General Services Administration, "login.gov - Homepage," login.gov/, accessed July 17, 2018; Social Security Administration, "How We Verify and Protect Your Identity," www.ssa.gov/myaccount/verifyandprotectid.html, accessed July 30, 2017.

[25.] Michael Graglia, Christopher Mellon, Evan

Akin, "Prerequisites for Incorporating Blockchain Into a Registry," FPR Blog, New America, July 31, 2017. https://www.newamerica.org/international-security/future-property-rights/blog/prerequisites-incorporating-blockchain-registry/, accessed March 9, 2018.

[26.] World Bank, "Indicators and a Monitoring Framework for Sustainable Development Goals: Launching a data revolution for the SDGs," http://indicators.report/targets/16-9/, accessed July 30, 2017.

[27.] https://en.wikipedia.org/wiki/Cryptographic_hash_function accessed March 1, 2017

[28.] Shafi Goldwasser and Mihir Bellare, "Lecture Notes on Cryptography," Massachusetts Institute of Technology, July 2008, http://cseweb.ucsd.edu/~mihir/papers/gb.pdf, accessed March 2018.

[29.] Craig Ball, "Deduplication: Why Computers See Differences in Files that Look Alike", Ball in your court: Musings on E-discovery and Computer Forensics (blog), July 8, 2015, accessed July 30, 2017.

[30.] The creators of dLoc, www.smartrac-group.com/dloc-a-breakthrough-solution-in-document-authentication.html, may point out that their product gets pretty close, and we agree, but the point remains. For more on hashing, see: Wikipedia, The Free Encyclopedia, s.v. "Hash function," accessed July 30, 2017, en.wikipedia.org/wiki/Hash_function.

[31.] Joon Ian Wong, "Sweden's blockchain-powered land registry is inching towards reality," Quartz, April 3, 2017, qz.com/947064/sweden-is-turning-a-blockchain-powered-land-registry-into-a-reality/, accessed July 30, 2017; Michael Graglia, "Tbilisi agreement heralds significant expansion of blockchain to manage property registries", FPR Blog (blog), New America, February 16, 2017, https://www.newamerica.org/international-security/future-property-rights/blog/blockchain-for-property-rights-georgia/, accessed July 30, 2017.

[32.] "Breaking the seals," The Economist, August 22, 2012, http://www.economist.com/node/21560242, accessed July 30, 2017.

[33.] Jeffrey Dorfman, "Creative Markets For Property Rights Can Solve Many Problems," Forbes, June 11, 2017, www.forbes.com/sites/jeffreydorfman/2017/06/11/creative-markets-for-property-rights-can-solve-many-problems/#751c0bfe4377, accessed July 30, 2017.

[34.] Wolfie Zhao, "$30 Million: Ether Reported Stolen Due to Parity Wallet Breach," CoinDesk, July 19, 2017, www.coindesk.com/30-million-ether-reported-stolen-parity-wallet-breach/, accessed July 30, 2017; Jordan Pearson, "Someone 'Accidentally' Locked Away $150M Worth of Other People's Ethereum Funds," Motherboard VICE, November 7 2017, https://motherboard.vice.com/en_us/article/ywbqmg/parity-multi-signature-wallet-vulnerability-300-million-hard-fork.

[35.] For an explanation of these terms, see Michael Graglia, "5 Myths About Blockchains," FPR Blog (blog), April 14, 2017, https://www.newamerica.org/international-security/future-property-rights/blog/5-myths-blockchains-registries/.

[36.] For the latest blockchain and ethereum transactions, see "Bitcoin Block Explorer," blockchain.info/, accessed July 30, 2017; "Etherchain - The Ethereum Blockchain Explorer," www.etherchain.org/, accessed July 30, 2017.

[37.] This is what Bitfury deployed in Georgia with their product Exonum. See "Exonum—A framework for blockchain solutions", exonum.com.

[38.] David Treat, "Editing the Uneditable Blockchain," Accenture, www.accenture.com/us-en/insight-editing-uneditable-blockchain, accessed July 30, 2017.

[39.] IPFS, "Peer-to-peer hypermedia protocol," 2015, GitHub Repository, github.com/ipfs/ipfs; Ethersphere, "swarm docs," github.com/ethersphere/swarm, accessed July 30, 2017.

[40.] Angela Walch, "The Path of the Blockchain Lexicon (and the Law)," Review of Banking &

Financial Law 36, (March 24, 2017): 715-765, papers.ssrn.com/sol3/papers.cfm?abstract_id=2940335, accessed July 30, 2017; Anthony Lewis, "A gentle introduction to the immutability of blockchains," Bits on blocks: Thoughts on blockchain technology (blog), February 29, 2016, accessed July 30, 2017.

41. "As-a-service Solutions Drive Growth in Global Sourcing Market," press release, July 2017, on ISG website, http://www.isg-one.com/related-case-studies-detail/as-a-service-solutions-drive-growth-in-global-sourcing-market, accessed July 30, 2017.

42. Microsoft Azure, "Blockchain on Azure," azure.microsoft.com/en-us/solutions/blockchain/, accessed July 30, 2017.

43. Maya Gainer, "From the Ground Up: Developing Jamaica's National Land Agency, 2000-2016," Innovations for Successful Societies, January 2017, successfulsocieties.princeton.edu/sites/successfulsocieties/files/MG_Land_Jamaica_May2017.pdf, accessed July 30, 2017.

44. "Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Driving Systems," SAE International, January 16, 2014. http://standards.sae.org/j3016_201401/, accessed on December 15, 2017.

45. "Path to Autonomy: Self-Driving Car Levels 0 to 5 Explained: Just what does 'Level 5 autonomous car' mean?" Car and Driver, October 2017. www.caranddriver.com/features/path-to-autonomy-self-driving-car-levels-0-to-5-explained-feature, accessed on December 15, 2017.

46. Here when we say "Notary" instead of the global definition of elevated attorney, we refer to the more American meaning of acknowledged signor.

47. "If you understand Hash Functions, you'll understand Blockchains," Talk Crypto (blog), Talk Crypto, November 28, 2016, http://www.talkcrypto.org/blog/portfolio/if-you-understand-hash-functions-youll-understand-blockchains/, accessed on December 15, 2017.

48. We say virtually because notarization in a legal sense includes authentication of signatures and indicates that the document is trustworthy. See National Notary Association, "What is Notarization," www.nationalnotary.org/knowledge-center/about-notaries/what-is-notarization. Hashing a document to a public chain only authenticates existence of the document in a certain condition at a given time. There is an open debate about if cryptographic signatures—using a private key on a personal device—are comparable to digital signatures.

49. Maurice Barbieri, Jean-Yves Pirlot, Dominik Gassen, Hanns-Jakob Pützer, Raul Radoi, Nicola Maria Hoischen, Florian Lebourdais, "Blockchain—Can This New Technology Really Revolutionize The Land Registry System?" Presentation, presented at Land and Poverty Conference, Washington, D.C., March 22, 2017, www.conftool.com/landandpoverty2017/index.php?page=browseSessions&form_session=547&presentations=show, accessed on January 15, 2017.

50. Ian Allison, "Blockchain-based Ubitquity pilots with Brazil's land records bureau," International Business Times, April 5, 2017, http://www.ibtimes.co.uk/blockchain-based-ubitquity-pilots-brazils-land-records-bureau-1615518, accessed on December 15, 2017; Michael Graglia, "Tbilisi agreement heralds significant expansion." www.newamerica.org/international-security/future-property-rights/blog/blockchain-for-property-rights-georgia/, accessed on December 15, 2017.

51. Staff Report, "Dubai Land Department."

52. "Landstream Summary 2018 (Public)," Dubai Properties and ConsenSys, February 2018, docs.google.com/document/d/10B3C4YGDTHHS-P7x61g13YNfvyCQkTXgVvxYfNI1OKc/edit.

53. "The underlying technology for this project is ChromaWay's two innovative products. First, Esplix the smart workflow middleware which enables processes and workflows to be described using code and then enforced by the participants in the system." See "Blockchain and Future House Purchases Second Phase Completed in March 2017," Chromaway,

chromaway.com/landregistry/, accessed January 15 2018.

54. Hariramchakraborthy Janakiraman, Chris T'en, Morag Home, and Rodolf Salem, "Distributed Ledger Technology and Bank Guarantees for Commerical Property Leasing, IBM, July 2017, www.ibm.com/industries/au-en/banking/downloads/Whitepaper-Bank_Guara.pdf, accessed on January 15, 2018.

55. "Landstream Abstract," Dubai Properties and ConsenSys, February 2018, drive.google.com/file/d/1FmrSywflp9AqluypbD_OZF-xlziyWDtY/view.

56. Real Estate ABC, "Escrow (Real Estate): What is it? Why do I need it? How does it work? Who chooses escrow?" www.realestate-abc.com/homeguide/Escrow.htm.

57. Nick Szabo, "Smart Contracts: Building Blocks for Digital Markets," University of Amsterdam, http://www.fon.hum.uva.nl/rob/Courses/InformationInSpeech/CDROM/Literature/LOTwinterschool2006/szabo.best.vwh.net/smart_contracts_2.html.

58. Andrew Hinkes, "Blockchains, smart contracts, and the death of specific performance," Inside Counsel, July 29, 2014, http://web2.insidecounsel.com/2014/07/29/blockchains-smart-contracts-and-the-death-of-speci, accessed on January 15, 2018.

59. "Propy Announces World's First Real Estate Purchase on Ethereum Blockchain," Cision, PR Newswire, October 2, 2017. www.prnewswire.com/news-releases/propy-announces-worlds-first-real-estate-purchase-on-ethereum-blockchain-300529474.html, accessed on December 14, 2017.

60. Natalia Karayaneva, "How A Smart Contract replaced An Escrow Company in a $60k deal," Hackernoon (blog), Medium, October 17, 2017, hackernoon.com/how-a-smart-contract-replaced-an-escrow-company-in-a-60k-deal-551ff7839044.

61. For more information on why a private permissioned chain is most appropriate here, see Michael Graglia et al., "Prerequisites for Incorporating Blockchain."

62. "In cooperation with DEWA, Smart Dubai, Emirates NBD, and the General Directorate of Residency and Foreigners Affairs," press release, October 11, 2017, on wasl Asset Management Group website, www.wasl.ae/press-releases/cooperation-dewa-smart-dubai-emirates-nbd-and-general-directorate-residency-and-foreigners-affairs.

63. Per interview with Bitfury, January 16, 2018.

64. "Property Investment for Under $100," Brickx, https://www.brickx.com/, accessed January 15, 2018.

65. "Stop Selling your Upside: How Blockchain Can Unlock Value in Real Estate Through Fractional Ownership," Pangea (blog), Medium, January 4, 2018, medium.com/@pangeaGO/stop-selling-your-upside-how-blockchain-can-unlock-value-in-real-estate-through-fractional-b492400b47a; "Real Estate Needs a Revolution," Pangea (blog), Medium, January 11, 2018, media.consensys.net/using-blockchain-to-expand-access-to-real-estate-4a2e3fb15f90.

66. Rod Thomas, "Blockchain's incompatibility for use as a land registry: issues of definition, feasibility and risk," European Property Law Journal 6, no. 3 (2017): 361-390, doi: https://doi.org/10.1515/eplj-2017-0021.

67. Title searches usually start from the last known issued title insurance policy which, given the frequency with which properties are transferred, typically limits the period that needs to be searched to thirty years or less.

68. James Schneider, "Profiles in Innovation: Blockchain, Putting Theory into Practice," Goldman Sachs, May 24, 2016, msenterprise.global.ssl.fastly.net/wordpress/2017/07/Goldman-Sachs-Blockchain-putting-theory-to-practice.pdf, accessed January 25, 2018.

69. Ibid.

70. Joseph Treaster, "Iowa Cuts Added Costs in Title Insurance Policies," New York Times, July 6, 2005, www.nytimes.com/2005/07/06/business/iowa-cuts-added-costs-in-title-insurance-policies.html.

[71.] "2016 Title Premium Volume Up 8.7 Percent," American Land Title Association, March 21, 2017, https://www.alta.org/news/news.cfm?20170321-2016-Title-Premium-Volume-Up-87-Percent, accessed March 15, 2018.

[72.] "Title Industry Generates $3.9 Billion in Premiums During Q3," American Land Title Association, December 14, 2017, https://www.alta.org/news/news.cfm?20171214-Title-Industry-Generates-39-Billion-in-Premiums-During-Q3, accessed March 15, 2018.

[73.] Jurisdictions in which evidence of ownership is provided by an Abstract of Title, a document detailing the chain of ownership of a property. In the sections that follow these are referred to as "abstract" jurisdictions and contrasted with Torrens jurisdictions, in which ownership is guaranteed by a government-backed Certificate if Title.

[74.] For example, competing claims based on possession of the land, e.g. adverse possession, are not valid under Torrens.

[75.] Shaun Watchie Perry, "Outline of the Torrens Act," American Bar Association, August 2005, https://www.americanbar.org/newsletter/publications/law_trends_news_practice_area_e_newsletter_home/torrenact.html.

[76.] The government's liability is not limited by the amount of money in this pool, and they would be required to pay claims with other funds if it was ever exhausted.

[77.] Justin T. Holl, Peter Rabley, Mark Monacelli, and David Ewan, "The Earthen Vessel: Land Records in the United States," paper presented at the PRIA Annual Winter Conference, Washington, DC, March 2010.

[78.] Ibid.

[79.] Aanchal Anand, Matthew McKibbin, and Frank Pichel, "Colored Coins: Bitcoin, Blockchain, and Land Administration," Cadasta, http://cadasta.org/resources/white-papers/bitcoin-blockchain-land/.

[80.] See World Bank, "Financial Inclusion," April 5, 2017, http://www.worldbank.org/en/topic/financialinclusion/overview, accessed March 1, 2018.

[81.] Pani Baruri, "Blockchain Powered Financial Inclusion," (PowerPoint slides) Cognizant, 2016, http://pubdocs.worldbank.org/en/710961476811913780/Session-5C-Pani-Baruri-Blockchain-Financial-Inclusion-Pani.pdf, accessed March 5, 2018.

[82.] tZero, "Home," https://www.tzero.com/#home, accessed March 5, 2018.

[83.] Chloe Cornish, "Overstock Chief explores sale to fund blockchain venture," Financial Times, December 13, 2017: https://www.ft.com/content/d4a6d698-dfa6-11e7-8f9f-de1c2175f5ce, accessed March 9, 2018.

[84.] Charles Gallo, Anna Jumamil, and Pak Aranyawat, Blockchain and Financial Inclusion: The role blockchain technology can play in accelerating financial inclusions (Washington, DC: Georgetown University Press, 2017), 8.

[85.] Pranab Ranjan Choudhury, Manoj Kumar Behera, Saumya Sharma, and Tajamul Haque, "Combining Administrative and Open Source Data for Monitoring Land Governance: Mapping Women Land Rights in the Context of UN's SDG in India," paper presented at the 2017 World Bank Conference on Land and Poverty, Washington, DC, March 2017.

[86.] Bryson Masse, "'Propy' gets $15M on promise of digital currency real estate investment," Inman, September 25, 2017, https://www.inman.com/2017/09/25/propy-gets-15m-promise-digital-currency-real-estate-investment/, accessed March 5, 2018.

[87.] Andrew Nelson, "De Soto Inc.: Where Eminent Domain Meets the Blockchain," Bitcoin Magazine, March 5, 2018, https://bitcoinmagazine.com/articles/de-soto-inc-where-eminent-domain-meets-blockchain/

[88.] Dominic Wilson, "Why the blockchain isn't enough to fix land registries," LinkedIn, February 26, 2018, https://www.linkedin.com/pulse/why-blockchain-isnt-enough-fix-land-registries-

dominic-wilson/, accessed March 9, 2018.

89. Christopher Mellon and Michael Graglia, "Peering into the Future: How Dual-Frequency Satellite Receivers Will Democratize Land Surveying," FPR Blog (blog), New America, March 23, 2017, https://www.newamerica.org/international-security/future-property-rights/blog/peering-future-how-dual-frequency-satellite-receivers-will-democratize-land-surveying/, accessed March 9, 2018.

90. Kevin Mwanza and Henry Wilkins, "African startups bet on blockchain to tackle land fraud," Reuters, February 16, 2018, https://www.reuters.com/article/us-africa-landrights-blockchain/african-startups-bet-on-blockchain-to-tackle-land-fraud-idUSKCN1G00YK, accessed March 9, 2018.

91. "Introducing the FOAM Protocol: The consensus driven map of the world," FOAM (blog), September 22, 2017 https://blog.foam.space/introducing-the-foam-protocol-2598d2f71417, accessed March 9, 2018.

92. Keith Johnson and Elias Groll, "U.S. Sanctions Weapon Is Under Threat—but Not From Bitcoin," Foreign Policy, January 24, 2018, http://foreignpolicy.com/2018/01/24/u-s-sanctions-weapon-under-threat-but-not-from-bitcoin-blockchain-dlt-petro/.

93. Molly Jane Zuckerman, "New US Bill Seeks to Fight Terrorist Use of Cryptocurrencies," Cointelegraph, January 17, 2018, https://cointelegraph.com/news/new-us-bill-seeks-to-fight-terrorist-use-of-cryptocurrencies, accessed March 5, 2018.

94. Ibid; HM Treasury, National Risk Assessment of Money Laundering and Terrorist Financing 2017 (London, 2017), 5, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/655198/National_risk_assessment_of_money_laundering_and_terrorist_financing_2017_pdf_web.pdf, accessed February 27, 2018.

95. Zuckerman, "New US Bill Seeks to Fight Terrorist Use of Cryptocurrencies."

96. There are several reasons for such proclivity. One is the lack of technological adoption, though this is likely due more to the availability of other funding sources than a lack of technical capability. It is certainly possible that this pattern will change. STEM-educated, technically proficient individuals—especially engineers—are statistically overrepresented in jihadist groups to a high degree. Some researchers posit a link between the concrete thinking of engineers and the moral rigidity of religious and political fanatics. See Diego Gambetta and Steffen Hertog, Engineers of Jihad: The Curious Connection between Violent Extremism and Education (Princeton: Princeton University Press, 2016).

97. See "Elliptic," https://www.elliptic.co/.

98. Julia Kollewe, "Bitcoin: UK and EU plan crackdown amid crime and tax evasion fears," Guardian, December 4, 2017, https://www.theguardian.com/technology/2017/dec/04/bitcoin-uk-eu-plan-cryptocurrency-price-traders-anonymity.

99. Johnson and Groll, "U.S. Sanctions Weapon Is Under Threat—but Not From Bitcoin."

100. Nathaniel Popper, Oleg Matsnev, and Ana Vanessa Herrero, "Russia and Venezuela's Plan to Sidestep Sanctions: Virtual Currencies," New York Times, January 3, 2018,https://www.nytimes.com/2018/01/03/technology/russia-venezuela-virtual-currencies.html.

101. Rene Chun, "Big in Venezuela: Bitcoin Mining, Atlantic, September 2017, https://www.theatlantic.com/magazine/archive/2017/09/big-in-venezuela/534177/; Popper et al., "Russia and Venezuela's Plan to Sidestep Sanctions."

102. Ankit Panda, "Cryptocurrencies and National Security," Council on Foreign Relations, February 28, 2018, https://www.cfr.org/backgrounder/cryptocurrencies-and-national-security

103. Kowelle, "Bitcoin."

104. Jamil Anderlini, "Surge in Chinese house-buying spurs global backlash," CNBC.com, February 25, 2015, https://www.cnbc.com/2015/02/25/surge-in-chinese-housebuying-spurs-global-backlash.html, accessed February 27, 2018.