
COMMENT

SMART CONTRACTS AND THE COST OF INFLEXIBILITY

JEREMY M. SKLAROFF[†]

“Smart contracts” are decentralized agreements built in computer code and stored on a blockchain. Proponents imagine a future where commerce takes place exclusively using smart contracts, avoiding the high costs of contract drafting, judicial intervention, opportunistic behavior, and the inherent ambiguities of written language.

These decentralized code-only contracts are part of a decades-long quest to eliminate supposed inefficiencies in traditional written agreements. Electronic data interchange (EDI), a contracting technology from the 1970s, was designed with the same goal and garnered similar fanfare. Commentators at the time imagined a revolution in the way firms transacted and a full shift away from anything resembling a paper contract. Ultimately EDI failed to achieve these goals—it empowered, rather than circumvented, human decisionmakers along with their “inefficient” way of forming agreements. In doing so, EDI successfully reduced some transaction costs while preserving efficient forms of contractual flexibility.

Smart contracts are indeed more technologically sophisticated than EDI. Smart contract scripting languages offer a broader range of operations and greater scalability. Smart contracts are capable of seamlessly integrating with the operational and financial systems at the core of modern firms, whereas EDI transactions occurred in very early digital environments that required human intermediaries. Proponents of

[†] Senior Editor, Volume 166, *University of Pennsylvania Law Review*. J.D. Candidate, 2018, University of Pennsylvania Law School; M.B.A. Candidate, 2018, The Wharton School; B.A. 2011, Columbia University. This piece would not have been possible without the guidance, advice, and support of Professor David Hoffman, who labored over many drafts of this Comment and offered invaluable suggestions throughout. Reuben Grinberg of Davis Polk & Wardwell provided thorough feedback and helped me understand the technical aspects of blockchain and cryptocurrency. Many thanks are due to the editors of the *University of Pennsylvania Law Review*, particularly Paul Stephan and Ian Weiss, who worked on this Comment. Finally, I am deeply grateful to my family—JBS, ASC, and JDS—for their unwavering support and for always encouraging me to follow my passion, wherever it may lead.

the smart contract revolution, therefore, do not describe the technology as a way to merely enhance human activity; they argue it can replace every stage of agreement formation and performance. From a purely technical standpoint, they might be right.

However, shifting away from human-language contracts creates new inefficiencies. These stem from three features of smart contracts: automation, which requires that every agreement be formed from fully-defined terms; decentralization, which conditions performance on verification by third parties; and anonymity, which eliminates the use of commercial context to give meaning to agreement terms. As a result, it is extremely costly to form smart contracts in a volatile environment or whenever there's a level of uncertainty surrounding the agreement.

On the other hand, semantic contracts are flexible. They enable parties to use performance standards, generally-defined contract terms, to create an enforceable agreement without requiring complete knowledge of what might happen in the future. Standards also allow parties to responsively incorporate commercial customs into their agreement, circumventing the need for explicit but redundant negotiation. And once their agreement is formed and executed, the parties are nonetheless free to dynamically shape their relationship through informal modifications or by selectively enforcing breaches. These two forms of flexibility—linguistic ambiguity, and enforcement discretion—create important efficiencies in the contracting process. By eliminating this flexibility, smart contracting will impose costs that are more severe and intractable than the ones it seeks to solve.

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INTRODUCTION

Technology promises to replace slow and imprecise paper institutions with efficient, digitized counterparts.¹ Contract law is a frequent target of these hopes.² Though contracts ostensibly provide relief from the inefficiencies of public law, creating stable and predictable rules with which parties can privately order their affairs, many claim that contract law is broken, and sorely in need of a “killer app.”

Such criticisms come from the academy and from practitioners alike. Scholars criticize the inconsistency of judicial contract interpretation and the unpredictability of remedies in cases of breach.³ Even more severe criticisms come from commerce and industry, the private parties for whom contracts are explicitly supposed to be efficiency-enhancing. They view contract drafting as being dominated by arbitrary complexity, empowering lawyers to sap businesses of time and money.⁴ Some of the most ferocious criticism comes from technology entrepreneurship, where time and money are both especially

¹ See Richard Barbrook & Andy Cameron, *The Californian Ideology*, 6 SCI. AS CULTURE 44, 44 (1996) (“Information technologies, so the argument goes, empower the individual, enhance personal freedom, and radically reduce the power of the nation-state. Existing social, political and legal power structures will wither away . . .”).

² See Harry Surden, *Computable Contract*, 46 U.C. DAVIS L. REV 629, 631-35 (2012) (noting that firms have designed technological solutions to manage the high cost of designing, implementing, and litigating contracts); Nick Szabo, *Smart Contracts: Formalizing and Securing Relationships on Public Networks*, FIRST MONDAY (Sept. 1997), <http://firstmonday.org/article/view/548/469> [<https://perma.cc/ED3B-646Z>] (proposing the concept of a smart contract and noting that the “digital revolution” will enable the creation of a new contract law for digital agreements).

³ See, e.g., Mark P. Gergen, *A Theory of Self-Help Remedies in Contract*, 89 B.U. L. REV. 1397, 1418-19 (2009) (comparing inconsistent common-law rules governing damages for breaches involving harm to real property and concluding that “there is no good reason” for their inconsistency). Stewart Macaulay, *Klein and the Contradictions of Corporations Law*, 2 BERKELEY BUS. L.J. 119, 125 (2005) (“[L]aw professors tend to rationalize the common law [of contracts] as consisting of hard core rules surrounded by a soft periphery of exceptions . . . Usually, there is no rule telling us when the core and when the periphery applies.”); Robert E. Scott, *The Death of Contract Law*, 54 U. TORONTO L.J. 369, 370 (2004) (“The peril that public contract law faces is that many contracting parties have chosen to exit the public system of legal enforcement in favour of less costly alternatives over which they have more control. The result is that *the law* of contract is suffering from stagnation and . . . irrelevance.”)

⁴ See Lawrence M. Friedman et al., *Law, Lawyers, and Legal Practice in Silicon Valley: A Preliminary Report*, 64 IND. L.J. 555, 555 (1989) (“What do lawyers contribute to technological change and economic development? . . . [V]ast amounts of legal time billed to corporate enterprise . . . are the pathological symptoms of an over-regulated, excessively litigious culture . . .”).

rare commodities, compared to more mature industries that have perhaps accepted the inevitability of complex contractual arrangements.⁵

With criticism concentrated in technology-forward industries, it's no surprise that technology is proposed as an answer. Indeed, the desire to redesign human affairs according to digital rules—motivated by a desire for transparency and efficiency, and an ideological distrust for human institutions—accompanies each era's major technological developments.⁶ The creation of elementary mainframe computers in the early Seventies inspired visions of governments and societies structured entirely around data flows and statistical modeling.⁷ It also hinted at revolutions in the internal organization of the firm, and in the ways that firms could interact externally. Developments in processing power and speed allowed firms to distribute computers throughout the business, creating information systems that were granular, accurate, and fast, driving new kinds of management decisionmaking.⁸ The maturation of the Internet transformed both the nature of commerce and the nature of society. But at each stage, the ultimate effect of disruptive technology is both more limited, and more unpredictable, than evangelists initially declare.⁹ The Internet has allowed for unprecedented access to knowledge and information, but also has enabled corporate concentration, government surveillance, and new types of control over consumers.¹⁰

This Comment analyzes smart contracts, a recent development in the quest to replace traditional contract law.¹¹ Smart contracts enable firms to

⁵ See Scott Edward Walker, *Top 10 Reasons Why Entrepreneurs Hate Lawyers*, VENTURE HACKS (Jan. 14, 2010), <http://venturehacks.com/articles/hate-lawyers> [<https://perma.cc/5AFV-PV4A>] (noting technology entrepreneurs' criticisms of lawyers for being poor listeners, too expensive, "deal-killers," and for "over-lawyering").

⁶ See generally 2 MANUEL CASTELLS, *THE POWER OF IDENTITY: THE INFORMATION AGE* (2d ed. 2009) (analyzing the sociopolitical landscape of contemporary technology).

⁷ See generally EDEN MEDINA, *CYBERNETIC REVOLUTIONARIES* (2011) (describing the creation of cybernetics, a field of social science dedicated to understanding how information systems affect society).

⁸ See E. Burton Swanson, *Information Systems Innovation Among Organizations*, 40 MGMT. SCI. 1069, 1069 (1994) (noting that the "widespread impacts of [information systems] on the businesses it serves are increasingly acknowledged to be fundamentally strategic").

⁹ See generally EVGENY MOROZOV, *THE NET DELUSION* (2011) (noting that despite its utopian aims, the Internet has provided powerful tools to authoritarian regimes).

¹⁰ See DAVID GOLUBIA, *THE POLITICS OF BITCOIN: SOFTWARE AS RIGHT-WING EXTREMISM* 6 (2016) ("[I]n the name of vague slogans like 'internet freedom', wealth and power have concentrated enormously as digital technology has spread all around the globe.").

¹¹ Because smart contracts are a relatively new phenomenon and continue to evolve rapidly, there is little existing literature applying traditional contracts concepts to blockchain technology. Kevin Werbach and Nicolas Cornell provide a useful overview of contract law relevant to smart contracts and touch briefly on the concept of flexibility expanded upon here. See *Contracts Ex Machina*, 67 DUKE L.J. (forthcoming 2017) (manuscript at 44-46), https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2936294 [<https://perma.cc/7ZYJ-GXAX>] (noting that smart contracts make it difficult to respond to a change in circumstances that occurs between the "ex ante specification of

transact without the need for law or courts. They can autonomously negotiate with other parties (or other parties' smart contracts), and then attach directly to the parties' information systems so that goods or payment promised by the contract are automatically delivered. According to the technology's more extreme advocates, smart contracts will revolutionize the way firms transact and may fundamentally transform our social and legal institutions. However, even if the technology is robust enough to enable such a change, its tangible effects on firms' interactions will be more nuanced than evangelists claim. In some instances, it will make transactions *more* expensive and inefficient than the traditional legal contracts it aims to replace.

This Comment proceeds as follows. In Part I, I explain the technology underlying smart contracts, trace its evolution from Bitcoin, and describe a sample smart contract in use today. In Part II, I analyze the importance of flexibility in the contracting process as a way to manage transaction costs. I focus on standards—roughly-defined contract terms that guide parties' behavior without precision—and on informal contract governance, which helps mitigate incentives for bad-faith litigation or other abusive behavior. In Part III, I compare smart contracts to electronic data interchange (EDI), an older contracting technology whose proponents also imagined would transform the fundamental nature of contracting. I argue that EDI's features actually enabled—and encouraged—parties to rely on flexibility and informal dispute resolution in their contracting process, whereas smart contracts make such flexibility impossible. Finally, in Part IV, I identify what exactly makes smart contracts so inflexible, and then anticipate some possible responses.

I. LEX CRYPTOGRAPHIA?

Today, a new technology dominates conversations about the future of social and commercial organization. Broadly labeled “decentralized ledger technology” (DLT), the term spans a group of cryptographic tools and protocols to exchange, verify, and secure data without the need for centralized intermediaries.¹² So-called “trustless exchange” is motivated by the same goals

contracts and the ex post adjudication of legal effects”). Levy observes that contracts do more than simply create enforceable agreements—there are important social aims accomplished by writing “unenforceable,” or “purposefully vague” terms, or by refusing to enforce enforceable terms—and that smart contract proponents ignore these dimensions. Karen E. C. Levy, *Book-Smart, Not Street-Smart: Blockchain-Based Smart Contracts and the Social Workings of Law*, 3 *ENGAGING SCI., TECH., & SOC'Y* 1, 6-7 (2017). As far as I know, this Comment is the first to compare flexibility in semantic contracts and smart contracts, identify the incentives and effects of smart contracts' inflexibility on trading partners, and to compare smart contracts to EDI.

¹² See Rob Marvin, *Blockchain: The Invisible Technology That's Changing the World*, *PC MAG* (Feb. 6, 2017), <https://www.pcmag.com/article/351486/blockchain-the-invisible-technology-thats-changing-the-wor> [<https://perma.cc/BUC2-JLVL>] (explaining that decentralized ledger technology applies a

as technologies that came before—autonomy from inefficient and corruptible institutions, an insistence on the primacy and desirability of private social ordering, and frustration with the law and lawyers.¹³ And as with those earlier technologies, DLT has attracted a curious mix of sophisticated global corporations and shadowy activists, placing IBM, Maersk, and JP Morgan alongside cryptoanarchists, cypherpunks, and black market drug kingpins.¹⁴

A. *The Rise of Bitcoin*

What unites these seemingly disparate groups is more than an interest in using DLT for information storage and exchange. DLT's earliest but most successful application to date is Bitcoin—a “cryptocurrency” built using DLT protocols to enable participants to create, store, and exchange money itself.¹⁵ Bitcoin's market capitalization has soared in the past year, reaching about \$20B in late 2016, and was the world's best performing currency during 2015.¹⁶ Bitcoin can be used as payment for hundreds of thousands of firms and

“decentralized network of ‘nodes’ that verify . . . every transaction” and “distributed ‘trustless’ consensus” to prevent fraudulent activity). “Nodes” are computers in a decentralized ledger system which participate in recording and verifying transactions.

¹³ See GOLUMBIA, *supra* note 10, at 22 (observing that Bitcoin's popularity is driven by an ideological belief that “computer-based expertise” is superior to all other forms of expertise, including economics and finance); see also Gabrielle Orum Hernández, *With Contract Automation, Ambition Doesn't Always Align with Reality*, LEGALTECH NEWS (Mar. 30, 2017), <http://www.legaltechnews.com/id=1202782521057> [<https://perma.cc/JAC4-QLGX>] (“The idea that smart contract technology based on a publicly available distributed ledger could take the place of powerful legal and financial industries has an incredible allure . . .”).

¹⁴ Typically, blockchain gains prominent media coverage when used in either groundbreaking corporate initiatives or in cutting-edge criminal enterprises. Compare Nathaniel Popper & Steve Lohr, *Blockchain: A Better Way to Track Pork Chops, Bonds, Bad Peanut Butter?*, N.Y. TIMES (Mar. 3, 2017), <https://www.nytimes.com/2017/03/04/business/dealbook/blockchain-ibm-bitcoin.html?mcubz=0> [perma.cc/V54C-5yu7] (noting that global corporations like IBM and Maersk are using blockchain to improve information collection and accessibility), with Nathaniel Popper, *The Tax Sleuth Who Took Down a Drug Lord*, N.Y. TIMES (Dec. 25, 2015), <https://www.nytimes.com/2015/12/27/business/dealbook/the-unsung-tax-agent-who-put-a-face-on-the-silk-road.html?mcubz=0> [perma.cc/5XNX-MXA6] (describing law enforcement efforts to identify and convict the operator of an international marketplace for illegal drugs which used Bitcoin to facilitate payments). “Cypherpunk” is a social movement which believes that privacy in the digital age must be created organically, rather than supplied by “governments or corporations.” Nicolas Wenker, *Online Currencies, Real-World Chaos: The Struggle to Regulate the Rise of Bitcoin*, 19 TEX. REV. L. & POL. 145, 148 (2014). Cypherpunks celebrate “cryptographic tools and protocols . . . that might lead to a loosening of government control,” such as Bitcoin, blockchain, and other ways to “shield[] digital messages and information.” *Id.*

¹⁵ The term cryptocurrency reflects the fact that transactions are accomplished and verified using cryptographic principles. For a high-level overview, see *A Gentle Introduction to Bitcoin*, BITSONBLOCKS.NET (Sept. 1, 2015), <https://bitsonblocks.net/2015/09/01/a-gentle-introduction-to-bitcoin/> [<https://perma.cc/UD3X-B6QN>] [hereinafter *Gentle Introduction*]. For a description of Bitcoin's mechanics relevant to smart contracts, see *infra* note 29 and accompanying text.

¹⁶ Garrick Hileman, *State of Bitcoin and Blockchain 2016: Blockchain Hits Critical Mass*, COINDESK (Jan. 28, 2016), <http://www.coindesk.com/state-of-bitcoin-blockchain-2016/> [<https://perma.cc/6X4H-TSR5>].

service providers, including Microsoft, Dell, Overstock.com, and even the Chicago Sun-Times.¹⁷ Bitcoin startups have attracted almost a billion dollars in venture capital funding.¹⁸

Bitcoin combined two key DLT features, popularizing the technology and forming a template for more advanced applications that followed. First, Bitcoin harnessed a decentralized tracking system—commonly referred to as a ledger—that makes it cheap to record transactions, but very costly to commit fraud. Bitcoin’s protocols reward participants who cooperate and punish opportunistic behavior,¹⁹ with the result that transactions in the system can be tracked and recorded with confidence. Technologically, this is accomplished using a “blockchain”—a way of recording and reconciling every transaction that has ever occurred, between every single participant, going back to the beginning of Bitcoin.²⁰ The responsibility of maintaining this giant global ledger lies with Bitcoin users themselves, who receive transaction fees or newly created Bitcoins for their efforts. This ensures that every Bitcoin user is working to update the ledger truthfully, creating a natural technological check against fraud.²¹ While the responsibility for updating the

¹⁷ *What Can You Buy with Bitcoin?*, COINDESK (Oct. 19, 2015), <http://www.coindesk.com/information/what-can-you-buy-with-bitcoins/> [<https://perma.cc/324W-YLEC>].

¹⁸ See Hileman, *supra* note 16.

¹⁹ A foundational definition of opportunism is “self-interest seeking with guile.” OLIVER. E. WILLIAMSON, *MARKETS AND HIERARCHIES* 255 (1975). A more recent definition is that opportunism is “aggressive selfishness [that] disregards the impact of [an actor’s] actions on others,” variously including “stealing, cheating, breach of contract, dishonesty [and] distorting data” Timothy G. Hawkins et al., *Antecedents and Consequences of Opportunism in Buyer-Supplier Relations: Research Synthesis and New Frontiers*, 37 *INDUS. MARKETING MGMT.* 895, 895 (2008). For a review of contract scholarship on opportunism, see Chapin F. Cimino, *The Relational Economics of Commercial Contract*, 3 *TEX. A&M L. REV.* 91, 107-08 (2015). Importantly, smart contracts attempt to make such behaviors prohibitively costly, and perhaps this is one of technology’s key motivations. However, this Comment argues that smart contracts police opportunism in an expensive, inefficient way, eliminating alternative approaches that preserve flexibility.

²⁰ See HENNING DIEDRICH, *ETHEREUM* 94 (2016) (“It’s not a blockchain if its copies are not stored, identically, across massively many computers Fundamentally, the data a blockchain holds is a *sequence of transactions*. And as of today it is essential that no transaction is ever forgotten.”); *id.* at 33 (“Blockchains do *symmetric* computation. Every node in a blockchain stores and computes the *same* data. The nodes even execute the exact same calculations at roughly the exact same moment in time.”).

²¹ A major opportunity for fraud in any digital-only currency is “double-spending.” With traditional physical currency, once Alice gives her dollar to Bob, she physically cannot spend that dollar again. With digital currency, Alice might be tempted to claim that her previously-spent Bitcoin still belongs to her. Bitcoin solves this problem by making it computationally inefficient to retroactively change a completed transaction. Alice would need to amass 51% of all the computing power in the Bitcoin network to successfully double-spend, which is both prohibitively expensive and would cause the price of Bitcoin to plummet when others discover the attempt. See Michael Abramowicz, *Cryptocurrency-Based Law*, 58 *ARIZ. L. REV.* 359, 379-80 (2016) (describing how an actor could successfully manipulate the blockchain, though at great cost, using a “51% attack”). Users who repeatedly attempt to defraud the Bitcoin blockchain are subject to an automatic ban. See Ghassan O. Karame et al., *Misbehavior in Bitcoin: A Study of Double-Spending and Accountability*, 18

blockchain is shared by every user, no single participant can control or modify Bitcoin transactions. Once a Bitcoin is spent (or lost) it is gone forever.²²

Second, Bitcoin enabled the instantaneous and direct transfer of value, obviating the need for banks or other institutions. A Bitcoin has no physical token counterpart²³—it is simply an arbitrary unit of information, a solution to a math problem that becomes more difficult over time at a pace coded into the protocol.²⁴ This information can be sent directly to other participants on the Bitcoin network without interference from either within or outside the network.²⁵ Bitcoin “wallets” are computer programs that keep track of a participant’s Bitcoins in a

ACM TRANSACTIONS ON INFO. & SYS. SECURITY 2:1, 2:21 (2015) (“Bitcoin nodes locally ban . . . the misbehaving user for 24 hours.”). However, such punishment may not be a sufficient countermeasure, since users can “modify/spoof their [IP addresses] or . . . connect to and attack other peers, who still haven’t blacklisted [the misbehaving user].” *Id.*

²² See Matthew Sparkes, *The £625m Lost Forever—the Phenomenon of Disappearing Bitcoins*, TELEGRAPH (Jan. 23, 2015), <http://www.telegraph.co.uk/technology/news/11362827/The-625m-lost-forever-the-phenomenon-of-disappearing-bitcoins.html> [<https://perma.cc/3VXk-5V6K>] (“Welsh IT worker James Howells famously lost 7,500 Bitcoins in 2013 when he accidentally threw out an old hard disk containing his private key. It is reportedly under thousands of tonnes of landfill at a waste recycling centre in Pillgwenlly, Newport.”). As of the time of writing, 7,500 Bitcoins would be worth almost \$45 million.

²³ Though Bitcoin is not a physical currency, it still requires an immense technological infrastructure. See Mark Gimein, *Virtual Bitcoin Mining Is a Real-World Environmental Disaster*, BLOOMBERG (Apr. 12, 2013), <https://www.bloomberg.com/news/articles/2013-04-12/virtual-bitcoin-mining-is-a-real-world-environmental-disaster> [<https://perma.cc/8U62-U6FJ>] (noting that Bitcoin miners use enough power every day to power half of the Large Hadron Collider).

²⁴ At a general level, a Bitcoin is generated using hashing algorithms, which enable the one-way transformation of data. *How Bitcoin Mining Works*, COINBASE (Dec. 22, 2014), <http://www.coindesk.com/information/how-bitcoin-mining-works/> [<https://perma.cc/8EGL-HLLB>]. Every transaction in the Bitcoin system is efficiently combined using a hash, capturing that data in a perfectly accurate way. *Id.* The resulting hash is unique to that set of transactions; if only a single previous transaction is slightly altered, the resulting hash of these transactions would be completely different. *Id.* Computers can easily verify that a given hash results from a given set of transactions. *Id.* To create a new Bitcoin, a Bitcoin “miner” discovers an alphanumeric string that, when combined with the already-existing hash of all transactions, generates a new string with a very specific property—it starts with a certain number of zeroes. Andreas M. Antonopoulos, *Mining and Consensus*, in BITCOIN & THE BLOCKCHAIN (2014), <http://chimera.labs.oreilly.com/books/1234000001802/cho8.html> [<https://perma.cc/BEQ7-CT37>]. The required number of zeroes increases over time, so that generating these solutions becomes increasingly difficult. *Id.* A full explanation of Bitcoin’s mechanics is beyond the scope of this Comment, but the important point is that a Bitcoin is just a piece of information, rather than a physically-existing object, and requires no offline support or verification.

²⁵ For example, if Alice wants to “send” Bob a Bitcoin that she owns, she’ll need three pieces of information: her Bitcoin’s address, roughly analogous to her bank account number; her private key, an alphanumeric string that verifies her ownership of the Bitcoin at that address, roughly analogous to a PIN; and a private key that creates a unique mathematical link. See *Gentle Introduction*, *supra* note 15. All three pieces of information are cryptographically locked into place once Alice completes the send request and inputs her private key. *Id.*

If Alice’s private key is lost, there’s no way for her to ever verify her ownership of that Bitcoin. If the private key is stolen by Charlie, now Charlie has access to the Bitcoin as well as Alice (presumably Charlie will immediately transfer it to a new address controlled by only him). Hence maintaining the security of the private key is extremely important.

graphically accessible way, but because a Bitcoin is simply a series of alphanumeric strings, it can also be “stored” using a piece of paper and a pencil.²⁶

Eventually, the number of new Bitcoins that can be created will drop to zero.²⁷ Hence Bitcoins are a currency only to the extent that the rest of the world finds them valuable and scarce. Judging by Bitcoin’s meteoric rise in price²⁸—and the growing number of firms dedicated to generating, storing, selling, and transacting in Bitcoin—the world finds them to be both.

B. *How to Lease a Car from an Anarchist*

By combining decentralization with instantaneous exchange, Bitcoin offered a rudimentary but compelling use of DLT. Today, however, blockchain protocols can do more than simply transmit and store Bitcoins. “Virtual machine” protocols now enable computer code to be embedded and executed in a blockchain itself, allowing for an incredibly complex range of operations to take place via the same underlying technology that accomplishes a Bitcoin transfer.²⁹ These operations can monitor the satisfaction of specified conditions, such as blockchain events (e.g., the completion of a Bitcoin transaction) or those that occur off-chain (e.g., data

²⁶ Bitcoin wallets can take a variety of forms, including software wallets, hardware wallets made from USB drives, and fully offline wallets. Bitcoin experts suggest avoiding software-only wallets since they are vulnerable to hackers or technical problems with the computer storing the Bitcoin addresses. *See, e.g., Cold Storage*, BITCOIN WIKI, https://en.bitcoin.it/wiki/Cold_storage [<https://perma.cc/9Y-69-DWR6>] (suggesting that users who own a significant amount of Bitcoins should “keep[] the majority of the reserve in *cold storage*, or in other words, not present on the web server or any other computer”).

²⁷ According to rules programmed into the Bitcoin protocol, no more than twenty-one million Bitcoins will ever be created. *What is Bitcoin?*, COINDESK (Mar. 20, 2015), <http://www.coindesk.com/information/what-is-bitcoin/> [<https://perma.cc/6BF9-E954>] (“The bitcoin protocol—the rules that make bitcoin work—say that only 21 million bitcoins can ever be created by miners.”).

²⁸ Though most of this rise might be due to speculation. *See, e.g.,* Nathaniel Popper, *Bitcoin Price Soars, Fueled by Speculation and Global Currency Turmoil*, N.Y. TIMES (Jan. 3, 2017), <https://www.nytimes.com/2017/01/03/business/dealbook/bitcoin-price-soars-fueled-by-speculation-and-global-currency-turmoil.html?mcubz=0> [<https://perma.cc/2DRE-4KXP>] (“[H]eavy trading on Chinese Bitcoin exchanges, much of it by automated software, suggests that most of the price movement is a result of bets by speculators.”).

²⁹ To be precise, this new generation of blockchain technology relies on a different protocol than Bitcoin. One major Bitcoin alternative is Ethereum, which provides a richer set of development options compared to Bitcoin’s relatively limited features. *See, e.g.,* Vitalik Buterin, *A Next-Generation Smart Contract and Decentralized Application Platform*, GITHUB, <https://github.com/ethereum/wiki/wiki/White-Paper> [<https://perma.cc/F8NP-8EZ6>] (“Ethereum is . . . an alternative protocol for building decentralized applications . . . with a particular emphasis on . . . the ability of different applications to . . . interact Ethereum does this by building . . . a blockchain with a built-in Turing-complete programming language, allowing anyone to write smart contracts and decentralized applications [with their] own arbitrary rules.”). Further, both Bitcoin and Ethereum have virtual machines, since both can process scripts. Diedrich, *supra* note 20, at 199. However, Ethereum’s virtual machine is far more robust and is therefore seen as the single, definitive virtual machine for building smart contracts. *Id.* at 202-03.

from an Internet-of-Things enabled device), interact with other functions, and generate more outputs than payment and non-payment.

To offer an analogy that might be helpful, consider the difference between text messaging and full-fledged websites. In the former case, text messages are either sent or not sent, based on a two-way line of communication between phones. In the latter, a variety of complex functions—responsible for rendering the visual layout of the website, verifying and communicating your identity with the site, pointing to other functions that exist elsewhere on the web, and so on—reside on your computer, on the site's server, or anywhere else. Not only can the website send and receive messages, but it can display media, alter and rearrange information, and communicate with other sites and devices.³⁰

Most blockchain applications to date have focused on modernizing the internal information apparatus of firms. An array of blockchain companies are offering products that make recordkeeping cheaper and more accurate, such as in healthcare data tracking, property registration, freight registration and tracking, supply chain management, and protecting intellectual property, among others.³¹ However, blockchain's more extreme evangelists imagine that

30 Though this analogy gives a sense of the increase in sophistication accomplished by blockchain virtual machines, it is misleading in an important respect. SMS messages are routed through cellular service providers which are at the behest of human executives, who themselves are susceptible to outside influence. See Jeremy Scahill & Margot Williams, *A Secret Catalogue of Government Gear for Spying on Your Cellphone*, INTERCEPT (Dec. 17, 2015, 12:23 PM) ("Most [of the devices] can be used to geolocate people, but the documents indicate that some have more advanced capabilities, like eavesdropping on calls and spying on SMS messages."). Websites exist on servers that are in the jurisdiction of one locale or another, and thus subject to both legal and illegal surveillance. See Aiden Warren & Alexander Dirksen, *Augmenting State Secrets: Obama's Information War*, 9 YALE J. INT'L AFF. 68, 74 (2014) (describing the NSA's PRISM program, which allowed intelligence agencies and law enforcement to view "email, video and voice chat, videos, [and] photos" as well as activity on platforms like "Microsoft, Yahoo, Google, [and] Facebook"). Blockchain networks exist outside the control of any individuals—much less CEOs—and at least theoretically beyond the state's legal reach.

31 See, e.g., Jamie Condliffe, *DeepMind's New Blockchain-Style System Will Track Health-Care Records*, MIT TECH. REV. (Mar. 9, 2017), <https://www.technologyreview.com/s/603828/deepminds-new-blockchain-style-system-will-track-health-care-records/> [<https://perma.cc/9WD9-GBWC>] (describing "a blockchain-style system that will carefully track how every shred of patient data is used"); Michael J. Casey & Pindar Wong, *Global Supply Chains are About to Get Better, Thanks to Blockchain*, HARV. BUS. REV. (Mar. 13, 2017), <https://hbr.org/2017/03/global-supply-chains-are-about-to-get-better-thanks-to-blockchain> [<https://perma.cc/P92X-U3R7>] ("[A] slew of startups and corporations are exploring a radical solution to this problem: using a blockchain to transfer title and record permissions and activity logs so as to track the flow of goods and services between businesses and across borders."); Ben Dickson, *Blockchain Could Completely Transform the Music Industry*, VENTUREBEAT (Jan. 7, 2017), <https://venturebeat.com/2017/01/07/blockchain-could-completely-transform-the-music-industry/> [<https://perma.cc/BD4L-FQNX>] ("Digital rights expression is one of the biggest problems the music industry is tackling presently . . . This is the first place we can expect blockchain to bring change."); David Z. Morris, *Maersk Tests Blockchain-Based Freight Tracking*, FORTUNE (March 5, 2017), <http://fortune.com/2017/03/05/272weden-tests-blockchain-based-freight-tracking/> [<https://perma.cc/6TYP-B6QT>] ("Maersk, the world's largest shipping company, has completed the first test of a system that would manage the company's cargos using blockchain, the

the technology will transform not only how firms organize internally, but also how they interact externally.³² If blockchain code can instantaneously effect an exchange of goods based on the satisfaction of specified conditions, why would firms rely on expensive, unpredictable agreements written in human language?

The appeal of “smart contracts,” agreements built in computer code and stored on a blockchain, is in many ways similar to that of Bitcoin and other early blockchain applications, harnessing the same critical features like decentralized consensus, instantaneous exchange, and complex computational states. A smart contract is immutable and unmodifiable once created, since its logic is seeded into a blockchain spread across multiple points.³³ This prevents powerful parties from opportunistically breaching the contract or extracting a beneficial modification that disadvantages weaker counterparties.³⁴ It is written and executed without the need for expensive intermediating institutions; by interacting with devices that monitor states of the world and with firms’ internal information systems, it can check whether conditions are satisfied and then instantaneously provide the bargained-for goods or money.³⁵ And it can exist either in isolation or be nested within multiple sets of other smart contracts, so that its complexity can scale up to meet whatever transaction logic the parties desire.

A seminal smart contract example is an automated car lease.³⁶ Suppose that Bob has a fleet of cars, one of which he wants to lease to Alice. Further suppose that in this world, cars can be operated by a digitally-enabled “key” such as a smartphone app, QR code, or fingerprint, which can be activated and terminated remotely. According to the smart contract, Alice provides down payment to Bob in exchange for use of his car for a set amount of time. Both Alice and Bob have pre-specified a bargaining logic based on their desired terms, such as lease length, interest rate, size of down payment, and

distributed ledger technology behind Bitcoin.”); Pete Rizzo, *Sweden Tests Blockchain Smart Contracts for Land Registry*, COINDESK (June 16, 2016), <http://www.coindesk.com/272weden-blockchain-smart-contracts-land-registry/> [<https://perma.cc/W3B6-ZCR5>] (“The government of Sweden is testing a system for registering and recording land titles that utilizes blockchain in a bid to digitize real estate processes.”).

³² DON TAPSCOTT & ALEX TAPSCOTT, *BLOCKCHAIN REVOLUTION* 95-117 (2016).

³³ See DIEDRICH, *supra* note 20, at 7 (“[Smart contracts] *cannot be stopped* . . . Blockchains are like a *force of nature*.”).

³⁴ Michael del Castillo, *Relax Lawyers, Nick Szabo Says Smart Contracts Won’t Kill Jobs*, COINDESK (Dec. 8, 2016), <http://www.coindesk.com/nick-szabo-lawyers-jobs-safe-in-smart-contract-era/> [<https://perma.cc/6RX3-U2JE>] (“The result is that while traditional law is relatively flexible, involving interpretation and judgment (and can therefore be corrupted), a software version is ‘rigid and predictable.’”). Literature about traditional contracts reflects similar concerns. See Cimino, *supra* note 19, at 124 (2015) (discussing common law and UCC rules on agreement modification and their effects on opportunistic behavior).

³⁵ Hernández, *supra* note 13 (arguing that “the hallmark” of a smart contract is for it to “operate without the need for human legal interpretation”).

³⁶ See Szabo, *supra* note 2 (“As another example, consider a hypothetical digital security system for automobiles. The smart contract design strategy suggests that we successively refine security protocols to more fully embed in a property the contractual terms which deal with it.”)

car specification. Bob runs a blockchain program that monitors his accounts and inventory, analyzes Alice's proposed terms, and then autonomously negotiates terms acceptable to both. Alice runs a similar blockchain program that monitors her personal accounts to ensure sufficient funds to pay for the lease. Both applications are authorized to bargain and enter into a smart contract for their respective owners.³⁷ Once the agreement is formed, Bob's smart contract discovers Alice's payment, chooses a car that matches her desired specifications, and instructs that car to accept her digital key.

Now, imagine that Alice fails to make an interest payment and falls into default. Not only could the smart contract respond by terminating her digital key, but it could activate a variety of other complex actions. It could terminate the key only until Alice cures her default. It could activate a bank's key so that the car can be repossessed. And it could monitor the car's activity once the breach is discovered, such that the car is not disabled while driving down the highway.³⁸

Even this relatively simple smart contract demonstrates the technology's disruptive potential. When parties can attach smart contracts directly to their property and money, and when autonomous negotiation agents are capable of manifesting the parties' intent to be bound, there is no need for courts to interpret or enforce agreements. Hence commenters have gone as far as predicting (and sometimes rejoicing at) the imminent death of contract law. Smart contracts "eliminate the need for legal enforcement;"³⁹ they represent "a technological alternative" to the legal system itself.⁴⁰ Smart contracts threaten "thousands of [legal] jobs"⁴¹ in the short term and "cast a stark light

³⁷ *Id.* (noting that "search and negotiation" constitute part of the smart contract); see also Florian Glatz, *How We Use Smart Contracts at SatoshiPay to Change the Internet's Economy Forever Today!*, MEDIUM (Feb. 1, 2016), <https://medium.com/@heckerhut/how-we-use-smart-contracts-at-satoshipay-to-change-the-internet-s-economy-forever-today-777988a868d> [<https://perma.cc/D6NG-CS4K>] (describing blockchain technology that enables "[web] browsers to become autonomous agents that negotiate and perform on contracts for their users").

³⁸ A version of this contract already exists, though in a pre-blockchain form. See Michael Corkery & Jessica Silver-Greenberg, *Federal Agency Begins Inquiry Into Auto Lenders' Use of GPS Tracking*, N.Y. TIMES (Feb. 19, 2017), <https://www.nytimes.com/2017/02/19/business/dealbook/gps-devices-car-loans.html> [<https://perma.cc/FE6J-RX52>] ("[T]he head of collections at a Louisiana credit union said he could monitor a vehicle's whereabouts on his smartphone and once disabled a borrower's ignition while shopping at a Walmart.").

³⁹ Werbach & Cornell, *supra* note 11, at 20.

⁴⁰ Alexander Savelyev, *Contract Law 2.0: 'Smart' Contracts As the Beginning of the End of Classic Contract Law*, 26 INFO. & COMMS. TECH. L. (forthcoming 2017) (manuscript at 21), https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2885241 [<https://perma.cc/6NMT-B38M>].

⁴¹ Rebecca Campbell, *New York City Law Firm Experiments with Blockchain Smart Contracts*, CRYPTOCOINS NEWS (Feb. 2, 2017), <https://www.cryptocoinsnews.com/new-york-city-law-firm-experiments-blockchain-smart-contracts/> [<https://perma.cc/3SF7-BRCZ>]; cf. del Castillo, *supra* note 34 (noting Nick Szabo's claim that lawyers will perform functions "complimentary" to smart contract formation).

on the future of the legal profession,”⁴² freeing contracts from intermediation by courts.⁴³ “Contracts written as immutable code on private blockchains” will ensure that transactions between firms “hum[] along harmoniously . . . self-executing and self-regulating.”⁴⁴

There are many other real benefits of smart contracting, covered at length by commentators who take a more reasoned approach.⁴⁵ Though a full discussion of those benefits is beyond the scope of this paper, some are worth mentioning. Agreements written in code and linked directly to firms’ information systems will reduce drafting and accounting costs for at least some agreements.⁴⁶ The cryptographic technology underlying blockchains provides a cheap and effective way to ensure the integrity of data. Payment via digital Bitcoin wallets reduces costs to both parties by minimizing reliance on intermediaries, spreading those costs across the entire decentralized network of blockchain participants. And by ensuring agreements are immediately and irrevocably performed, smart contracts lower the cost of monitoring performance and may sidestep the need for litigation in some situations.

But there is more to a contract than recordkeeping and rote performance. A written contract memorializes an understanding between parties such that it becomes a legible agreement enforceable by a court.⁴⁷ While such contracts are not the only type of enforceable agreement, they are the most efficient way to ensure that the court correctly understands what parties were willing to exchange under their deal.⁴⁸ That understanding can be essential when the court needs to supplement or correct the agreement. And, as we will see, these documents provide parties with important tools to manage uncertainties inherent in the agreement process and responses if the agreement goes wrong.

⁴² James Eyers & Misa Han, *Lawyers Prepare for ‘Driverless M&A’ as Smart Contract Era Dawns*, FIN. REV. (June 19, 2016), <http://www.afr.com/technology/lawyers-prepare-for-driverless-ma-as-smart-contract-era-dawns-20160616-gpknyz> [<https://perma.cc/K3SM-TPJV>].

⁴³ See Joshua A.T. Fairfield, *Smart Contracts, Bitcoin Bots, and Consumer Protection*, 71 WASH. & LEE L. REV. ONLINE 35, 39 (2014), <http://scholarlycommons.law.wlu.edu/wlulr-online/vol71/iss2/3/> [<https://perma.cc/H5RH-83SG>] (“If financial transactions can be freed of banks as intermediaries, then contracts can be freed of courts as intermediaries.”).

⁴⁴ Matt Byrne, *Do Lawyers Have a Future?*, LAWYER (Sept. 20, 2016), <https://www.thelawyer.com/issues/online-september-2016/do-lawyers-have-a-future-2/> (last visited Mar. 13, 2017).

⁴⁵ See, e.g., TAPSCOTT & TAPSCOTT, *supra* note 32.

⁴⁶ See, e.g., Marco Iansiti & Karim R. Lakhani, *The Truth About Blockchain*, HARV. BUS. REV. (Jan.–Feb. 2017), <https://hbr.org/2017/01/the-truth-about-blockchain> [<https://perma.cc/JZV4-UQY4>] (“Firms are built on contracts, from incorporation to buyer-supplier relationships to employee relations. If contracts are automated, then what will happen to traditional firm structures, processes, and intermediaries like lawyers and accountants?”).

⁴⁷ 1 E. ALLAN FARNSWORTH, FARNSWORTH ON CONTRACTS § 7.2 (2d ed. 1990).

⁴⁸ See Ronald J. Gilson et al., *Text and Context: Contract Interpretation as Contract Design*, 100 CORNELL L. REV. 23, 26 (2014) (noting that parties use written contracts to restrict attempts to add or modify obligations).

On the other hand, smart contracts are more like apps than contracts, fully collapsing the distinction between agreement formation and execution.⁴⁹ Whereas legal agreements must be voluntarily performed (or compelled through court order), smart contracts are composed of computer code permanently lodged in a blockchain. That code executes automatically and reliably once the parties' chosen conditions have been satisfied. And since its terms have been decentralized and distributed to every blockchain node,⁵⁰

⁴⁹ See DIEDRICH, *supra* note 20, at 3 (“Blockchains collapse agreement and execution. Because a *smart contract* both is the agreement and *executes* it. In business, governance, and law. They are ‘collapsed’ into one thing, not just simplified or packaged together.”). According to some commentators, a smart contract isn’t a smart contract at all—it is merely a computer program that performs a pre-existing agreement, which itself was made pursuant to traditional contract law. See, e.g., Cheng Lim et al., *Smart Contracts, Bridging the Gap Between Expectation and Reality*, OXFORD BUS. L. BLOG (July 11, 2016), <https://www.law.ox.ac.uk/business-law-blog/blog/2016/07/smart-contracts-bridging-gap-between-expectation-and-reality> [<https://perma.cc/6P5K-7L53>] (“The term ‘smart contract’ is a misnomer. A smart contract shares some theoretical similarities with a legal contract . . . but it is important to note where those similarities start and end.”). Regardless of where one draws the line between a “contract” and a “performance mechanism,” there are still unique costs of smart contracts that semantic contracts avoid. See Anthony Macey, *What’s in a Name?—The Disambiguation of Smart Contracts*, MEDIUM (July 8, 2016), <https://medium.com/@anthonymacey/whats-in-a-name-the-disambiguation-of-smart-contracts-daca8276db4> [<https://perma.cc/6P5K-7L53>] (noting that smart contracts and traditional legal contracts have different goals and describing possible permutations of the two).

⁵⁰ The extent of decentralization in blockchain varies. At one end of the spectrum are permissionless blockchains, like Ethereum or Bitcoin. There, anyone can perform or verify transactions once they install the correct software. DIEDRICH, *supra* note 20, at 100. On the other end of the spectrum are permissioned blockchains, typically intended for enterprise use. For example, Quorum is a blockchain being developed by JP Morgan for interbank transactions. It adopts the core Ethereum architecture but makes certain changes to enhance privacy of network participants. See JP Morgan Chase, *Quorum Whitepaper*, GITHUB, <https://github.com/jpmorganchase/quorum-docs/blob/master/Quorum%20Whitepaper%20v0.1.pdf> [<https://perma.cc/DAH3-CHBY>] (proposing a modification of Ethereum for enterprise use). And, importantly, it only admits certain preapproved entities as participants. *Id.* On permissioned blockchains, on-chain activity is durably linked to off-chain identity. DIEDRICH, *supra* note 20, at 194.

The permissionless/permissioned distinction has important effects on agreement flexibility. Transactions on permissionless blockchains systems are expensive, slow, and irreversible, due to the enormous number of participants verifying and processing the governing code. High participation is what provides the benefit of maximum decentralization—replacing costly or corruptible intermediaries with user-driven consensus. Vitalik Buterin, *On Public and Private Blockchains*, ETHEREUM BLOG (Aug. 7, 2015), <https://blog.ethereum.org/2015/08/07/on-public-and-private-blockchains/> [<https://perma.cc/8AQ2-NFDP>] [hereinafter Buterin, *Private Blockchains*] (explaining that “if we have a domain name system on a blockchain, and a currency on *the same blockchain*, then we can cut costs to near-zero with a smart contract”). But it is also what ensures that smart contracts cannot be undone or flexibly modified.

On the other hand, transactions on private blockchains are verified quickly and cheaply. *Id.* In these systems, certain participants are designated as more trusted than others, a feature built directly into the protocol itself. Whereas in public blockchains, transactions must be confirmed by a majority of participants—an enormous number of individual processes in the case of Ethereum—transactions in permissioned blockchains can be successfully processed by just a few trusted nodes. *Id.* Fewer required confirmations means lower transaction fees and speedy confirmation. *Id.*

However, the advantages of private blockchains exist in tandem with reliance on offline identity. A private blockchain maintained by JP Morgan, for example, requires that participants *know* that

there is no room for “second thoughts . . . arm twisting or delayed payments.”⁵¹ The terms exist independently of the parties, with a blockchain guaranteeing and enabling their performance.⁵² As a result, the transactional relationship created by a smart contract between two firms must be completely formed and precisely defined, eliminating forms of flexibility that are crucial to the contracting process. In this sense, the transaction costs of entering into smart contracts may actually be higher than those associated with traditional semantic contracts.

There are two sources of such costs. First, smart contracts create negotiation costs by requiring parties to fully and precisely define all future states of the contract. Such definition may be impossible,⁵³ such as when parties are contracting in volatile or uncertain environments, or redundant, such as when parties abide by the same trade customs or commercial practices. In traditional contracts, parties can manage these costs by using standards—loosely-defined contract terms that take on more precise meaning during the course of performance.⁵⁴ Smart contracts foreclose on such tools by requiring that every term is explicit and precise before execution takes place.⁵⁵

Second, smart contracts raise the costs of responding to breach by removing enforcement flexibility. Parties that cannot build bespoke contracts prefer to avoid litigation and resolve contract disputes informally. Litigation over generic contracts is unpredictable and extremely costly, incentivizing parties to bootstrap their relationship—their history of business and the

the bank's super-nodes are indeed operated by the bank, and that participants consent to be bound by the bank's governance decisions. Whenever the bank wants to change some technical feature of the blockchain it can do so unilaterally. *Id.* And, more to the point, the bank can undo or modify transactions on the blockchain at will. *Id.* As a result, participants on permissioned blockchains are typically bound by “off-chain, real-world agreements.” DIEDRICH, *supra* note 20, at 195. A blockchain built using offline identity, and buttressed by the power of traditional semantic contracts, is thus able to better withstand the transaction costs discussed throughout this Comment.

Offline institutions—in this case, market reputation as a source of trust, and semantic contract construction as a source of dispute resolution—do some of the work accomplished by system-wide consensus in permissionless chains. This makes smart contract purists uncomfortable, driving passionate debate about whether permissioned chains are a good development. Buterin has observed a “backlash from those who see [permissioned chains] as either compromising the whole point of decentralization or being a desperate act of dinosaurish middlemen trying to stay relevant.” Buterin, *Private Blockchains*, *supra*.

In general, this Comment analyzes smart contracts in permissionless systems. These provide the most striking contrast to traditional agreement formation. For readers interested in transaction dynamics in permissioned blockchains, some of this Comment's observations about EDI would apply—both systems are forms of transaction automation that use offline activity to solve the costs of inflexibility.

⁵¹ DIEDRICH, *supra* note 20, at 168.

⁵² *Id.*

⁵³ See Szabo, *supra* note 2, at 8 (discussing the effect of “mental transaction costs” on defining and drafting a contract); see also *infra* notes 64–72 and accompanying text.

⁵⁴ See *infra* notes 73–80 and accompanying text.

⁵⁵ See *infra* notes 138–145 and accompanying text.

promise of more business in the future—as a cheap way to constrain opportunistic behavior.⁵⁶ Smart contracts remove these informal strategies from parties' range of responses to breach. Once initialized, a smart contract creates a permanent and unalterable link between the terms of the contract and the information systems it manipulates, lasting until the transaction is complete. Without the ability to flexibly enforce their agreement, parties who determined that custom legal agreements were too expensive will instead be forced to rely on customized and equally-expensive blocks of code.⁵⁷

Though the rise of smart contracts is surely part of a broader "*Lex Cryptographia*"—an awakening to the power of decentralization and digital exchange⁵⁸—it is also part of a much longer project to replace contracts and contract law with a tool that is supposedly more efficient. One specific technology—electronic data interchange (EDI)—promised in the 1970s some of the very same things that smart contracts do today. Its proponents imagined EDI would go beyond a recordkeeping and data storage tool. They too thought that it could be used to enable firms to autonomously and instantaneously form contracts with each other, based on electronically-generated terms that dynamically reflected inventories and funds. In other words, EDI's evangelists imagined that it was a killer app for contract formation and execution.⁵⁹

With the benefit of hindsight, we know this project was ultimately unsuccessful. Firms did not replace traditional contracts with EDI networks then, and they will not replace contracts with smart contracts today. But EDI is different from smart contracts in fundamental ways. As we will see, certain features⁶⁰ of EDI actually enhanced flexibility and therefore improved contracting efficiency in ways that smart contracts cannot. Hence EDI did enjoy limited success by helping parties resolve conflicts cheaply and without litigation.

⁵⁶ See *infra* notes 97–108 and accompanying text.

⁵⁷ See *infra* note 142–58 and accompanying text. One counterargument is that code can be open-sourced and therefore cheaper for parties to integrate. For a response to this argument, asserting that the open-sourced nature of smart contracts actually results in additional costs, see *infra* notes 163–170 and accompanying text.

⁵⁸ See Aaron Wright & Primavera De Filippi, *Decentralized Blockchain Technology and the Rise of Lex Cryptographia* (Mar. 10, 2015) (unpublished manuscript), <https://ssrn.com/abstract=2580664> [<https://perma.cc/Z2MU-XG5F>] (analyzing the “benefits and drawbacks of this emerging decentralized technology”).

⁵⁹ See BENJAMIN WRIGHT, *THE LAW OF ELECTRONIC COMMERCE* 11 (1991) (“[T]he day of ‘interactive’ EDI is coming Futurists see the day when computers negotiate. One computer will offer to buy 500 widgets, and the second counteroffers with 300. The first will accept the counteroffer to form a contract.”); see also *infra* notes 110–137 and accompanying text.

⁶⁰ More precisely, EDI's lofty features were incompletely implemented. Were EDI to be built using the same sophistication and technology available to smart contracts today, it would have similar weaknesses.

II. FLEXIBILITY AND SEMANTIC CONTRACTS

Smart contracts are useful because they eliminate the possibility of breach, forcing parties to honor their original agreements.⁶¹ This quality reduces the amount of resources each party needs to monitor the other and avoids the high cost of litigation.⁶² Thus, smart contracts enable “trustless” transactions, agreements in which parties are secure without a formal legal contract.⁶³

But these benefits are costly. Parties to a smart contract must sacrifice flexibility, which is an important source of efficiency in their transactional relationship. In this Part, I detail how such flexibility operates in traditional semantic contracts, both during the negotiation and drafting of contract terms, and then at breach. First, I argue that standards—ambiguous terms like “commercial reasonableness”—help parties defer the costs of precisely defining their desired performance. This kind of semantic flexibility has two benefits. It helps parties contract through uncertain or volatile environments, creating an agreement that becomes more precisely defined as parties learn more about future states of the contract. It also helps parties avoid unnecessary negotiation over trade customs, which are difficult to precisely define but which nonetheless strongly influence parties’ behavior.

Then, I argue that semantic contracts also give parties enforcement flexibility. The ability to easily change contract terms helps parties avoid high drafting and renegotiation costs. I argue that this kind of flexibility enables parties to avoid unpredictable outcomes and bad faith litigation, thus preserving business relationships.

A. Contracting Through Uncertainty

Traditional contract law is premised on the “classical image of the bargained-for, state-contingent contract,” in which parties anticipate all future states of the contract and agree on terms that appropriately manage those risks.⁶⁴ However, parties can never reduce the universe of their

⁶¹ See Wright & De Filippi, *supra* note 58, at 24-25 (“[A]mbiguity and poor drafting can . . . be used by parties to wrestle free from contractual conditions that parties no longer want to honor [Parties] can use a smart contract to ensure that a contractual condition is executed, forcing the parties to remain bound to their respective obligations.”). For a discussion of what makes smart contracts unmodifiable, see *infra* notes 138–145 and accompanying text.

⁶² See Wright & De Filippi, *supra* note 58, at 26 (“In a system regulated by self-enforcing smart contracts . . . there is less of a need for judicial enforcement, because the way in which the rules have been defined—the *code*—is the same mechanism by which they are enforced.”).

⁶³ There are also a variety of what might be termed second-order benefits of smart contracts, including transforming the nature of the firm, harnessing the efficiencies of open-source software development, and enabling new kinds of dispute adjudication. I assess these benefits in Part IV.

⁶⁴ Gilson et al., *supra* note 48, at 33. This is the view of textualism, which supports the formalist interpretation of contracts based purely on terms in the agreement as opposed to the parties’ broader

agreement to fully-defined terms *ex ante*. It is impossible to completely predict events that may complicate performance, and even when events or outcomes can be defined *ex ante*, the parties' potential responses are too complex to model with static contract language.⁶⁵ A more realistic model of agreement formation is that parties use standards, rather than precisely defined terms, to "approximate" a state-contingent contract.⁶⁶

Parties in an uncertain environment—for example, one threatened by technological disruption or market volatility—face two contradictory costs in the contracting process.⁶⁷ First, there are *ex ante* costs of drafting and negotiating over precise terms. These costs increase with uncertainty as parties must use greater resources to learn more about the future state of the world, and because greater uncertainty suggests a higher risk that their predictions will be wrong.⁶⁸ Second, there are anticipated litigation costs. If the parties' precise predictions are incorrect, they may be driven to claim in bad faith that the contract was defective, or to opportunistically breach the contract and force suit.⁶⁹

Avoiding these costs places parties in a double bind. If parties deploy precise terms in a fully integrated contract, they raise *ex ante* negotiation and research costs but lower *ex post* incentives to litigate.⁷⁰ Discrete, integrated contracts discourage courts from fully examining the parties' business relationship and often enable resolution on summary judgment.⁷¹ Conversely, parties can minimize their *ex ante* costs by drafting terms that will likely be

behavior, with some exceptions. Textualists argue for a "hard" parol evidence rule" and for restrictions on when a court can deem contract terms in need of supplemental interpretation. *Id.* at 55.

⁶⁵ See Charles J. Goetz and Robert E. Scott, *Principles of Relational Contracts*, 67 VA. L. REV. 1089, 1091 (1981) ("[Standards are used where] parties are incapable of reducing important terms of the arrangement to well-defined obligations . . . [due to their] inability to identify uncertain future conditions or because of inability to characterize complex adaptations adequately even when the contingencies themselves can be identified in advance.").

⁶⁶ See Gilson et al., *supra* note 48, at 58 (discussing how parties can approximate a state-contingent contract when, for example, they can "anticipate the context in which performance will occur").

⁶⁷ See *id.* at 55 (defining uncertainty as the disruption of "commercial practices" by "changes in technical possibilities and market conditions").

⁶⁸ See *id.* at 56 ("[S]pecific rules covering possible outcomes . . . come[] at the cost of an increased likelihood that the *ex ante*-specified state contingencies will turn out to be incomplete or simply wrong *ex post*").

⁶⁹ See *id.* (noting that in a fully-defined but ultimately inaccurate contract there is an "incentive for the party disfavored by the contract's outcome" to engage in "opportunistic litigation driven by moral hazard").

⁷⁰ See *id.* (noting that "a complete . . . contract that specifies *ex ante* the outcome in each future state of the world" narrows a court's examination of the broader context of the agreement in possible future litigation).

⁷¹ See *id.* at 42 ("If . . . a court decides to consider additional context evidence, it must necessarily deny a motion for summary judgment . . . legally sophisticated commercial parties prefer [fully-integrated contracts] so that disputes can be resolved without the punishing costs of a full trial.").

inaccurate or by leaving such terms out of the agreement altogether, though the latter option does increase their ex post costs of litigation.⁷²

Alternatively, parties can use performance standards as a middle ground. Performance standards, a form of semantic flexibility, allow parties to contract without completely defining adequate performance ex ante.⁷³ Rather than leave a term undefined or potentially wrongly defined, parties can use concepts like commercial reasonableness to approximate their transactional goals.⁷⁴ Standards gain meaning through the “unique, interdependent relationships” that form a transactional context.⁷⁵ Standards are also vulnerable to ex post litigation, but parties can manage those costs using contractual tools to specify an interpretive scope tuned to the characteristics of industry practice and to the transaction itself.

For example, consider a contract to hire a sales agent. The contract may specify minute aspects of the agent’s behavior, but it cannot describe *every* action the agent must take during the life of the contract. Requiring that the agent make “commercially reasonable efforts” to sell a product is preferable to a term that attempts to be absurdly comprehensive, or one that merely requires that the agent “sell the product.”⁷⁶ The hirer’s ex ante gain in certainty about the agent’s actions under the contract outweighs the ex post cost of litigation over reasonableness.⁷⁷

This balance occurs when performance can be more easily evaluated ex post by a court than ex ante by the parties. When parties draft with specificity, they are choosing to evaluate performance themselves at the time of drafting. When parties use performance standards, they are calling on courts to evaluate performance later in time. Empirical evidence indicates that courts are willing to assign meaning to vaguely defined terms using the parties’ transactional context, and only rarely find a contract unenforceable due to ambiguity.⁷⁸ However, judicial enforcement of standards is limited to circumstances where

⁷² See *id.* at 57 (“[T]he greater the ex ante uncertainty, the potentially more important the ex post resort to standards and therefore to context, but with the increased potential for judicial mistake and opportunistic-motivated litigation.”).

⁷³ See Goetz & Scott, *supra* note 65, at 1127 (noting that standards reflect “uncertainty about factual conditions during performance and an extraordinary degree of difficulty in describing specifically the desired adaptations to contingencies”).

⁷⁴ Other examples of contractual standards include best effort clauses, fiduciary duties of agents to principals, and the performance of obligations in good faith. See *id.* at 1104, 1127, 1139.

⁷⁵ *Id.* at 1092.

⁷⁶ See Gilson et al., *supra* note 48, at 60-65 (noting that a “commercially reasonable efforts” clause may be used where a party’s actions are “dependent on the sequential outcome of uncertain events”).

⁷⁷ For a discussion of specific transaction costs involved with best efforts clauses, and contractual tools to manage them, see Goetz & Scott, *supra* note 65, at 1112-26.

⁷⁸ *Id.* at 1120 (citing *Bloor v. Falstaff Brewing Corp.*, 454 F. Supp. 258, 266-67 (S.D.N.Y. 1978), *aff’d*, 601 F.2d 609 (2d Cir. 1979)).

their use is the result of ex ante uncertainty, rather than the choice to “discard[] verifiable information” that could have been used cheaply.⁷⁹

The decision between precision and standards is not binary, but forms a spectrum of options that parties can adapt to the risk of judicial misinterpretation. If a transaction’s context is clear and occurs within an industry with concrete transactional norms, the risk of misinterpretation is low.⁸⁰ Participants in a more ambiguous context can increase contract specificity by defining the relevant industry, practices, and transactions against which the court should interpret the standard.⁸¹ Thus, performance standards provide parties with the benefit of “hindsight,” enabling transactions that could not occur if complete specificity were required.⁸² They provide semantic flexibility tailored to parties’ particular industries and transactional contexts.

B. *Avoiding Redundant Negotiation*

Performance standards can also lower negotiation costs by providing a way for parties to loosely reference prevailing trade customs or commercial practices. Parties gain the benefit of terms they would have mutually chosen anyway, without having to write and bargain for those terms explicitly.⁸³

Every agreement has a broader commercial context that affects parties’ perceptions of their obligations.⁸⁴ Parties incur negotiation costs to minimize the risk of bona fide misinterpretation or bad-faith litigation. But commercial context is amorphous. Even parties that ostensibly subscribe to the same custom may define it differently.⁸⁵ The costs of drafting a precise term that

⁷⁹ Robert E. Scott, *A Theory of Self-Enforcing Indefinite Agreements*, 103 COLUM. L. REV. 1641, 1654-55 (2003) (reviewing cases and finding that courts enforced incomplete agreements where parties “were forced to cope with problems of hidden action and hidden information”).

⁸⁰ See Gilson et al., *supra* note 48, at 62-67 (noting that contractual specificity will vary based on the clarity of the agreement’s “subject matter, industry, and surrounding circumstances”). Importantly, such practices should be both easily identified and easily verified by the court. Otherwise there are high incentives for parties to falsely claim the existence of a commercial practice if it supports their position in litigation. *Id.* at 57.

⁸¹ *Id.*

⁸² *Id.* at 62. When uncertainty becomes great enough, parties will forego a contract entirely and build forms of informal information exchange. *Id.* at 57-62 (“At some point, uncertainty becomes so pervasive that the parties cannot anticipate or specify the relevant context ex ante even through the invocation of broad standards . . . [those parties] forgo both text and context . . . by resorting to collaborative contracting.”).

⁸³ Clayton P. Gillette, *Interpretation and Standardization in Electronic Sales Contracts*, 53 SMU L. REV. 1431, 1438 (2000) (“[P]arties to the trade understand and accept the risk allocation made by the custom because it generates the same result to which they would have agreed if there had been explicit allocation.”).

⁸⁴ See Cimino, *supra* note 19, at 97 (“[C]ontracting actors [are] aware of each other, aware of their community, aware of the self and other’s place in their community, and aware that this moment is only one moment in time . . . Thus, no economic exchange—no transaction, no contract—lacks a relevant social background.”).

⁸⁵ See Gillette, *supra* note 83, at 1442 (“[E]ven transacting parties may have different interpretations of the custom they both purport to follow.”).

completely captures the relevant aspects of customary behavior are prohibitively high.⁸⁶ Instead, parties use implicit, functional versions of customs to inform their transactional goals and behavior.⁸⁷ Despite disagreement at the margins, this functional and implicit understanding permeates most participants in a given industry.⁸⁸

Standards enable parties to reference trade customs without the precision required for other contract terms.⁸⁹ When courts enforce custom-based standards, they create a valuable “public good” that defrays negotiation and drafting costs incurred by participants in their industry while providing parties with the outcome they expect.⁹⁰ This also creates a “judicial insurance policy” that applies to trade practice standards, policing against abusive behavior with no need for parties to specifically define breach.⁹¹

Importantly, such standards are not mandatorily or uniformly enforced in every agreement. Parties can opt for fully-defined performance terms where appropriate, and can use textual tools like integration clauses to control the scope and direction of a court’s inquiry when it attempts to interpret a standard.⁹² Merger clauses, for example, restrict a court to a plain meaning interpretation of some sections of the contract.⁹³ Parties textually define their shared understanding of the relevant context by explaining their business goals and situating the transaction in an industry context.⁹⁴ Agreements that

⁸⁶ *Id.* at 1443 (noting that attempting to precisely define a custom “increases exponentially the possibility of conflicts . . . or the incorporation into a contract of a trade usage of which one of the parties was unaware”).

⁸⁷ *Id.* at 1438 (“[T]rade customs [are] sufficiently regularized among members of the trade so that negotiation is no longer necessary to agree on the term that is the subject of the custom.”).

⁸⁸ *Id.* (noting that despite “superficial similarity between the [customary] terms that each party uses” there is a residual likelihood of misunderstanding).

⁸⁹ See Goetz & Scott, *supra* note 65, at 1104 n.31 (arguing that standards allow parties to harness the courts’ interpretation rules, providing the benefit of “common or typical risk allocations . . . [without] the expense of bargaining” to create those risk allocations).

⁹⁰ Gilson et al., *supra* note 48, at 44.

⁹¹ *Id.* at 36 (noting that a standards-based contract “comes with a judicial insurance policy permitting the replacement or enrichment of contract terms that, viewed in what the court believes to be the proper context, have ill-served the parties’ intentions”).

⁹² *Id.* at 42 (“[P]arties [can] economize on contracting costs by shifting costs from the back end of the contracting process . . . where a court would inquire broadly into context, to the front end of the contracting process (the negotiating and design function) where the parties specify the extent to which context will count.”).

⁹³ *Id.* (“Parties can [control future litigation costs], for example, by drafting a merger clause that integrates their entire understanding, including relevant context, into the written contract and then having the court apply a plain meaning interpretation to those contract terms that are facially unambiguous.”).

⁹⁴ *Id.* at 58 (“Discursive exposition of [the parties’] goals, expectations, and business plans, whether in the contract’s preamble or in particular sections, can supplement precise specifications of outcomes while still constraining a court’s discretion to range more widely than the parties want.”).

effectively specify relevant commercial context are also easier to resolve on summary judgment, reducing incentives to litigate.⁹⁵

These tools can be scaled to be more or less specific and can be crafted to govern the entire contract or certain sections. The same term may take on different meanings in different contexts, depending on the contracting environment and litigation risks. The result is that parties construct an “interpretive regime” molded to their transaction’s unique characteristics.⁹⁶ This semantic flexibility is absent from the computer code that composes smart contracts.

C. Enforcement Flexibility

A second form of flexibility occurs when parties enforce semantic contracts. Litigation is a risky and expensive outcome for all parties to a contract. When faced with dispute over an agreement, courts sift through the transaction, the parties’ history, and relevant commercial context to construct the contract that both parties intended.⁹⁷ This process can cause more damage than breach itself.⁹⁸ Commercial customs are notoriously hard to define and even the parties involved may not be fully aware of a custom’s popularity or precise boundaries.⁹⁹ Courts themselves are rarely capable of accurately determining and applying customs, and there is evidence that they prefer not to even try, relying instead on “interested party testimony and unsupported assumptions of reasonable commercial behavior.”¹⁰⁰ Highly sophisticated parties thus prefer fully integrated contracts that permit only minimal judicial interpretation, since the costs of such intervention might be especially large.

But trading parties range in sophistication and so do their ways of memorializing agreements. Agreements typically involve both written and unwritten terms. The balance of formal and informal governance measures depends on the parties’ transactional objectives, their level of familiarity and expectations for future transactions, their trust in each other, and the size and

⁹⁵ *Id.* at 41-42 (noting that a dispute over a fully integrated agreement can be resolved on summary judgment, reducing enforcement costs).

⁹⁶ *Id.*

⁹⁷ *Id.* at 36 (noting that some “[c]ontextualist jurisdictions . . . reject the notion that words in a contract can have a plain or unambiguous—context free—meaning at all” resulting in the admission of extrinsic evidence of the transaction’s context).

⁹⁸ *Id.* at 42 (“[P]arties will rationally invest in sufficient drafting costs [to insure that a court interpreting the written document . . . will be able to arrive at the ‘correct interpretation’ Here the simple comparison is between the costs of drafting and the costs of a trial.”).

⁹⁹ See *supra* notes 83–85 and accompanying text.

¹⁰⁰ See Gilson et al., *supra* note 48, at 90.

value of the contract.¹⁰¹ Parties to less formal agreements who nonetheless find themselves in litigation face both the high costs of legal fees and the high risks of judicial misinterpretation. Less integrated contracts require courts to examine a much wider range of transactional and commercial context.

As a result, parties may choose to resolve contract disputes informally. This takes the form of dynamic modification of contract terms based on verbal understanding rather than written amendments, selective enforcement of contract terms, or voluntary adoption of new obligations. Such recourse preserves parties' ongoing business relationship and the promise of future transactions, enabling them to proceed according to commercial norms¹⁰² rather than immediately resorting to expensive and unpredictable litigation that often destroys their ability to transact.¹⁰³

Despite this preference for informal contract governance, the mere presence of an enforceable, litigable contract stabilizes the transaction. Litigation as a worst-case option ensures that the parties' obligations under an agreement will, if necessary, be provided with an authoritative judicial interpretation.¹⁰⁴ Evidence suggests parties who rely primarily on "gentlemen's agreements" are more likely to end up in court because they do not understand their respective duties.¹⁰⁵ Familiarity with how the general contours of a written agreement would function in court—even if the document itself is unsophisticated—is associated with less litigation.¹⁰⁶

Hence the presence of a litigable document and the option not to enforce it are inherently valuable. For highly sophisticated parties to customized contracts, the ability to constrict the judicial interpretive process reduces the incentive to litigate and enhances predictability. For less sophisticated parties relying on a combination of boilerplate and transactional norms, the "background threat of

¹⁰¹ See Catherine Mitchell, *Contracts and Contract Law: Challenging the Distinction Between the 'Real' Deal and the 'Paper' Deal*, 29 OXFORD J. LEGAL STUD. 675, 678 (2009) (reviewing research about the relationship between the "legal and non-legal measures . . . governing transactions").

¹⁰² *Id.* at 679 (noting the distinction between "relationship preserving norms" like flexible agreement modification and the use of courts to enforce legal agreements).

¹⁰³ See Stewart Macaulay, *Non-Contractual Relations in Business: A Preliminary Study*, 28 AM. SOC. REV. 55, 55-67 (1963) (noting that some contracting parties view legal agreements with skepticism and as detrimental to commercial relationships).

¹⁰⁴ See Alessandro Arrighetti et al., *Contract Law, Social Norms, and Inter-Firm Cooperation*, 21 CAMBRIDGE J. ECON. 171, 186 (1997) ("The vast majority of firms saw both the use of writing and the attachment of legal force as important means of clarifying the agreement and providing for security in the event of a dispute.").

¹⁰⁵ See Mitchell, *supra* note 101, at 688 (reviewing research on firms that prefer to rely on informal agreements, which found that "use of looser commitments, particularly based on interpersonal relationships, could often be a source of disputes").

¹⁰⁶ See *id.* ("[I]t was in fact participants' knowledge of law and legal processes that made recourse to law unnecessary.").

possible legal action” guards against opportunistic behavior, while the option *not* to litigate allows those transactional norms to flourish.¹⁰⁷

Thus, parties can use both formal and informal obligations, as well as fully-defined contract terms and generally-defined standards, to create an agreement tuned to their transactional history, commercial practice, and market risks.¹⁰⁸ When smart contract proponents dismiss traditional contracting for being too unpredictable, messy, or time-consuming—in other words, for being too human—they overlook the reality that every transaction and every set of trading partners is unique. Each grapples differently with the challenge of fully-specifying performance *ex ante* and the pressure to informally modify agreements. Contractual flexibility, driven by the richness of semantic expression and the power of human judgment, provides an efficient way to manage those costs.

III. FLEXIBILITY AND ELECTRONIC DATA INTERCHANGE

Smart contracts and EDI are both part of a larger project to replace the complex and ambiguous nature of language contracts with something more efficient. However, the two tools accomplish this project to different degrees. EDI’s replacement of human contracting was incomplete because it was not technically robust enough to support a full range of business logic or deeply integrate with participants’ information systems. Hence it enhanced the human elements of contracting while making certain activities supporting the agreement—such as recordkeeping and report creation—more efficient.

On the other hand, blockchain not only enables information to be stored, accessed, and secured according to infinitely complex business rules. It also connects smart contracts to the information systems responsible for executing those business rules. A vision of autonomous business entities, operating without human oversight, is not far-fetched.¹⁰⁹ At the least, the possibility requires us to think about what is gained or lost as human businesses rely more and more on automated contract creation.

In this Part, I recount the history of EDI and analyze claims made by its proponents. I argue that these commenters were perhaps correct, though for

¹⁰⁷ *Id.* at 689.

¹⁰⁸ For example, parties agreeing to innovation contracts frequently create formal governance mechanisms for their relationship but rarely intend for them to be enforced by courts. Such contracts are particularly delicate and relationship-intensive, and the possibility of judicial intervention can stymie the formation of trust. *See* Cimino, *supra* note 19, at 126 (“[R]emoving the threat of enforcement in [innovation agreements] at the early stages of the parties’ relationship is critical to create an environment likely to take the relationship from the innovation stage to the production stage.”).

¹⁰⁹ *See* TAPSCOTT & TAPSCOTT, *supra* note 32, at 126-130 (describing a “distributed autonomous enterprise . . . powered by blockchain technology and cryptocurrencies, where autonomous agents can self-aggregate into radically new models of the enterprise”).

the wrong reasons: EDI was indeed a powerful new way to transact, but primarily as a result of processes it *failed* to replace. EDI did not transform the nature of business by making firms more rational and automated. Instead, it preserved flexible decisionmaking and empowered human managers, enabling more dynamic business relationships and more efficient transactions.

A. *The Vanguard of Electronic Contracting (in 1969)*

Frustrated with “excess complexity” in contracting, a Boston-area lawyer set out to standardize and categorize contract terms.¹¹⁰ His efforts—accomplished on a bottom-of-the-line personal computer with eight kilobytes of RAM¹¹¹—launched IBM’s law and computers division in 1969.¹¹² He created a standardized language to describe and categorize contracts electronically, which encapsulated data like who was covered by the contract, actions accomplished by the contract, and contract conditions.¹¹³ Computer programmers used that language to enable computers to interact with and manipulate contracts, and when coupled with the proliferation of personal computers throughout businesses, contract logic could be embedded and tracked throughout a firm’s operational chain.¹¹⁴ Eventually entire industries sought to standardize the way such programs structured and understood contracts so that firms could use EDI to communicate with each other.¹¹⁵

Once contracts were rendered in computer-readable code, they could be dynamically modified based on the parties’ positions. For example, an EDI system

¹¹⁰ See Charles F. Goldfarb, *The Roots of SGML—A Personal Recollection*, SGML SOURCE (1996), <http://www.sgmlsource.com/history/roots.htm> [<https://perma.cc/CX29-QEJN>] (discussing the history of Standard General Markup Language and its role in contract simplification and integration with information systems).

¹¹¹ The computer was an IBM 1130. *Id.* An iPhone 7 Plus has three gigabytes of RAM, approximately 375,000 times as much RAM as in an IBM 1130. A computer capable of efficiently mining Bitcoin typically has four gigabytes of RAM.

¹¹² See *id.*

¹¹³ See Lawrence A. Cunningham, *Language, Deals, and Standards: The Future of XML Contracts*, 84 WASH. U. L. REV. 313, 320-21 (2006) (describing “[s]oftware programmed to . . . recognize . . . tags [like] price and quantity”). For a discussion of how structured computer-readable code contrasts with traditional semantic contracts, see Surden, *supra* note 2, at 648-50.

¹¹⁴ See Cunningham, *supra* note 113, at 320 (noting that EDI systems could “direct [a] computer to perform prescribed functions . . . [like] posting or accepting offers on those terms and confirming resulting contracts via email.”); see also WRIGHT, *supra* note 59, at 9-10 (noting that “unlike data on or in paper, fax, telex or e-mail, which can only be read by humans and must be rekeyed” into a firm’s various software systems, “a computer receiving an EDI purchase order can understand that the message is an order . . . without human intervention, [the EDI system can] log the order into the recipient’s order-fulfillment, product-shipping, and accounting programs” autonomously).

¹¹⁵ See Cunningham, *supra* note 113, at 321 (describing commercial efforts to deploy EDI, which “required significant financial investment in related infrastructure and standard-setting processes to promote compatibility”). By the early 1990s, 15,000 firms used EDI across thirty countries. WRIGHT, *supra* note 59, at xxvii, 22.

could help a buyer and a supplier maintain an ongoing contractual relationship, with quantities and prices determined dynamically.¹¹⁶ This system could also respond to contingencies under the contract that were specified in advance, such as late arrival of goods, defective goods, or late payment.¹¹⁷ “[I]n principle,” at least, an EDI system could automate the formation and execution of “all the other transactional parameters that people contract about . . . using computer programs that ‘negotiate’ with each other and enter into ‘agreements.’”¹¹⁸ The result was “a revolution” in commerce, in that the “supreme and ubiquitous” medium for forming agreements—paper—would finally be eliminated.¹¹⁹

B. Business Processes as Computer Code

Forcing business relationships through the precise logic of computer code would also reduce firms’ economic and business risks. According to proponents, the specificity of EDI commands—grounded in fully-articulated “if-then” rules—would eliminate transactional ambiguities that tend to cause litigation.¹²⁰ Product availability and descriptions were standardized, continually updated, and always accurate.¹²¹ This minimized transaction costs by lowering the amount of resources firms had to spend to find each other, understand product specifications, and confirm sales.¹²²

Commentators also imagined that EDI could have beneficial effects on decisionmaking in general. Requiring managers to fully specify contract logic *ex ante* would force them to consider potential deals more critically. Accordingly firms could avoid “unprofitable” contracts and minimize their need to opportunistically breach.¹²³ The ability to enforce a chain of command through user permissions in computer systems would clarify which managers in a firm had final authority to approve and execute a contract, avoiding

¹¹⁶ See Margaret Jane Radin, *Humans, Computers, and Binding Commitment*, 75 *IND. L.J.* 1125, 1131 (2000) (noting that EDI could be deployed to intelligently order “supplies that are routinely needed at certain points in a [production] process”).

¹¹⁷ See *id.* (noting that EDI systems, rather than contracts between parties, have been used to manage events like late delivery or defective shipments).

¹¹⁸ *Id.*

¹¹⁹ WRIGHT, *supra* note 59, at xxvi.

¹²⁰ See Jane Winn, *The Impact of XML on Contract Law and Contract Litigation*, 5 (Nov. 17, 2005), <http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.101.7055&rep=rep1&type=pdf> [<https://perma.cc/E59A-XY9V>] (arguing that EDI enabled “[s]tandardization and machine execution” which resulted in “lower than average litigation rates” by “enhanc[ing] the effectiveness of business contracting processes”).

¹²¹ See WRIGHT, *supra* note 59, at 22-23 (noting that EDI replaced invoicing and the “paper model” of inventory management altogether).

¹²² See Gillette, *supra* note 83, at 1431 (noting that EDI “breaks down geographical, language, and institutional obstacles that impede the formation of what would otherwise be efficient contracts”).

¹²³ See Winn, *supra* note 120, at 5 (noting that EDI forced businesses to “specify[] in advance” the prices at which they would and would not execute an agreement).

another potential source of litigation.¹²⁴ More broadly, replacing human decisionmaking with “machine processes” would eliminate human error and “increase the rationality of [the] business.”¹²⁵

As ultimate proof of EDI’s success, commentators observe that “no litigation concerning EDI-formed contracts occurred” in the technology’s forty-year history.¹²⁶ One explanation is that EDI’s technological features—those that improved the contracting process, and those that affected firm operations in general—forced firms to fully commit to transactions in advance, and reduced ambiguities wherever possible.¹²⁷

C. Computer Code as Human Decisionmaking

However, another explanation is that EDI systems enabled firms to flexibly rely on their existing business relationships.¹²⁸ EDI systems were easily modifiable, but expensive and formed bilaterally with other firms.¹²⁹ Hence they were built out of a preexisting “relationship of trust” but could be adjusted as the parties’ relationship changed.¹³⁰ These features enabled EDI systems to approximate the role of semantic and enforcement flexibility in traditional written contracts.

¹²⁴ See *id.* (stating that “compliance with management policies could be enforced more effectively” using EDI than in the traditional contracting process); see also Szabo, *supra* note 2 (noting that smart contracts will enable firms to “convert[] many implicit employee contracts to more explicit smart contracts based on more direct relationships between owners (or at least their directors) and employees, and symmetric formalizations between employees”).

¹²⁵ Winn, *supra* note 120, at 5.

¹²⁶ Cunningham, *supra* note 113, at 321 (“In EDI’s four-decade history, no litigation concerning EDI-formed contracts occurred.”); see also Winn, *supra* note 120, at 5 (“Given the large volume of [business-to-business] EDI contracts formed in the U.S., it is surprising that there is not a single reported case involving an EDI contract.”).

¹²⁷ Winn, *supra* note 120, at 5-6 (reviewing the argument that EDI’s features have enabled business processes to become “more formally rational”).

¹²⁸ See *id.* at 6-7 (arguing that the lack of EDI-related litigation is due not only to improved process accuracy, but also greater ability to engage in informal conflict resolution and high incentives to do so).

¹²⁹ *Id.* Most EDI systems were formed bilaterally between firms. WRIGHT, *supra* note 59, at 11 (“EDI can travel directly between the sender’s and receiver’s computers . . . via (1) the physical delivery of a computer tape containing the data . . . or (2) a link through the telephone or some other telecommunications system.”). For an example of bilateral EDI in the healthcare billing context, see *id.* at 23 (describing an EDI system created by Baxter Healthcare Corporation, in which counterparties had to install specially-designed computers “that were connected only with [Baxter’s] order entry system”). Interestingly, there was a push in certain industries to create open EDI standards that would generate economies of scale. See *id.* at 10-11 (“Large industry committees set public EDI standards . . . [Public] [s]tandards setting is a slow, expensive, bureaucratic process An industry group, such as the Automotive Industry Action Group, may [accordingly] develop guidelines for EDI implementation within its [own] industry.”). In a certain sense, this same debate is being replayed in the context of permissioned versus permissionless blockchains. See *supra* note 50 and accompanying text.

¹³⁰ Winn, *supra* note 120, at 6.

Modification of EDI systems was cheap and could dynamically incorporate contractual or relationship changes. Managers directly involved in business processes, not “judges or . . . attorneys,” were the key transactional decisionmakers. EDI freed managers from “the luxury (or as some would say, misfortune) of a hovering lawyer.”¹³¹ Instead, managers were empowered to continually optimize contract terms or to make relationship-preserving concessions.¹³²

Not only did EDI enable counterparties to harness their business relationship in contract creation—it actually encouraged them to do so. Parties were reluctant to invest in costly EDI systems without commitments from their counterparties to participate in those systems.¹³³ EDI was also not easily interoperable from business to business, so such investments were highly relationship-specific and required familiarity with technical aspects of counterparties’ other information systems.¹³⁴ High investment costs reduced the threat that parties would defect from the cooperative EDI trading arrangement and resort to litigation instead. If a party did choose to litigate, it would have to write off the cost of its EDI investment and terminate the business relationship with its counterparty. These disincentives were especially steep when an EDI system connected a powerful party with a weaker party, which characterized many EDI arrangements.¹³⁵

In this sense, EDI was successful because it harnessed the same types of flexibility that are so important to traditional, semantic contracts. EDI systems were easily modified and could replace as much or as little of parties’ existing, traditional contractual relationship as desired. It disincentivized litigation while providing ways to resolve business or transactional disputes cheaply and responsively.¹³⁶ EDI’s strength was therefore not its precision or autonomy, but its lack thereof. Though EDI failed to fully replace “the paper model” for forming transactions, it made some related activities faster and

¹³¹ WRIGHT, *supra* note 59, at 35.

¹³² Winn, *supra* note 120, at 6 (noting that EDI trading partners operated within a “tacit agreement” to resolve disagreements or technical glitches); *see also* WRIGHT, *supra* note 59, at 35 (noting that “manager brain power” is a “supreme and irreplaceable” resource for designing and executing transactions).

¹³³ Winn, *supra* note 120, at 4 (“[I]t is relatively expensive to establish a [business-to-business] EDI system[], and businesses are reluctant to spend the money required to establish EDI communications in the absence of a relationship of trust that antedates the use of the technology.”).

¹³⁴ *Id.* at 6 (discussing the strategic impacts of relationship-specific investment in the context of EDI); *see also supra* note 129 and accompanying text (describing bilateral, private EDI systems).

¹³⁵ *See* Winn, *supra* note 120, at 5-7 (noting that EDI commonly connected small or medium sized businesses with large multinational corporations).

¹³⁶ *See* WRIGHT, *supra* note 59, at 323 (noting that EDI systems enable parties to speed up negotiations by providing focus on “a few key issues, that, if addressed . . . provide both parties a reasonable degree of certainty and fairness” on terms and conditions); *see also* Surden, *supra* note 2, at 682 (noting that parties to electronic contracts “tolerat[e] a tradeoff in [ex-post] flexibility for [ex-ante] efficiency” since they can later rely on a “legal decision-maker” should an unplanned contingency occur).

more efficient.¹³⁷ However, its most important contribution was empowering the human judgment of management decisionmakers.

IV. INFLEXIBILITY IN SMART CONTRACTS

EDI emerged when information technology was only beginning to saturate businesses, and when telecommunication was extremely limited. Conversely, smart contracts are being built in environments of full digitization, in which all aspects of firm operations, from production to payment to bookkeeping, are linked to digital systems. This technical sophistication creates the possibility of truly automated contract formation and execution. Paradoxically, it also makes smart contracting more expensive and less efficient than traditional semantic contracts in environments when there is ex post uncertainty, or where parties prefer to avoid drafting highly customized agreements.

In this Part, I argue that these greater costs stem from three features of smart contracts: they must be written in precise, fully defined computer code; they are unmodifiable once executed; and they favor anonymous and one-off transactions. I anticipate responses to these critiques, reviewing some current events in blockchain politics. Finally, I argue that these limitations are not merely theoretical concerns. The lack of flexibility in smart contracts presents a major challenge to the technology's scalability.

A. Precision, Decentralization, and Anonymity Create Unique Costs

Computer code must be precisely and completely defined, because at root it is a series of if-then instructions that must all be resolvable by a computer. A smart contract cannot contain a term that has one meaning at the time of execution and takes on another meaning later. Moreover, the only modifications that can be made to smart contracts are those that were built into the original contracts as dormant alternatives.¹³⁸ Hence such modifications can only be made

¹³⁷ See WRIGHT, *supra* note 59, at 23 (“As experience [with EDI] grows further, users abandon the paper model. They electronically relay information . . . that would have been impractical to exchange on paper.”). In fact, EDI partners would frequently enter into EDI trading agreements—traditional, semantic contracts that structured their use of EDI. *Id.* at 321. This is another example of parties using a paper contract to create an “interpretive regime” to govern the particular risks of their transaction, as in Part II. In this case, an EDI trading agreement could be used to avoid adverse outcomes under UCC § 2-207. See *id.* at 319-21 (noting that EDI users opted to use trading agreements to preclude the possible application of buyer-favored UCC gap-fillers).

¹³⁸ Bill Marino & Ari Juels, *Setting Standards for Altering and Undoing Smart Contracts*, in RULE TECHNOLOGIES: RESEARCH, TOOLS, AND APPLICATIONS, 151, 163 (Jose Julio Alferes et al. eds., 2016) (explaining that smart contracts can be modified either by “turn[ing] ‘on’” terms that were “included in the initial contract in an ‘off’ state” or by using “pointers” to “call out to . . . satellite contracts” created “at the outset” to represent “certain [alternative] function-terms”). A smart

if the parties explicitly contemplated at the outset that they might want to make those particular modifications later, and only if they are able to expend the resources required to negotiate and draft those modifications correctly.

For example, suppose a vendor and a purchaser enter into an ordinary, written contract and develop a business relationship that they would both like to preserve. Then suppose at some point the vendor sends the customer low-quality goods, and wants to compensate the customer by granting her a 60-day extension on late payment. This payment flexibility was not included in the original written contract, because it would have been infeasible for the parties to negotiate *ex ante* about such a specific hypothetical situation. But, if the parties now wish to modify their original agreement, they can expend the modest resources required to negotiate and execute that change in writing. And if modifying the written agreement is too time-consuming and expensive, the parties can achieve the benefits of such a modification simply by agreeing verbally and implementing the change, leveraging their ongoing business relationship as a source of trust.

This flexibility would not have been an option if the agreement were a smart contract. To defer payment for sixty days, the parties would need to draft a whole new smart contract incorporating the change. Even if the new negotiation is only focused on a single sixty-day extension, it necessarily raises new bargaining points, like what happens if there is another low-quality shipment. Perhaps the parties could have minimized these costs by including a renegotiation feature in the initial smart contract. But this solution simply shifts the costs of modification from mid-performance to the drafting stage.¹³⁹ These costs are

contract that attempts to call on a second contract chosen during execution results in a non-deterministic function. See Erik Zhang & Da Hongfei, *Reconstructing Smart Contracts Part I. The Ghost of Undeterminism*, MERKLE (Mar. 24, 2017), <https://themerkle.com/reconstructing-smart-contracts-part-1/> [<https://perma.cc/TU5S-DJEE>] (“Dynamic Calls refer to a situation in which a program calls a second program, which can only be determined when running. Since the call target of a Dynamic Call is only decided when running, its actions are rendered un-deterministic.”). Non-deterministic smart contracts are not technically viable.

¹³⁹ See Michael del Castillo, *Donald Trump's Transition is a Trial Run for Smart Contracts*, COINDESK (Dec. 6, 2016), <http://www.coindesk.com/blockchain-builders-can-thrive-donald-trumps-america/> [<https://perma.cc/QL2-6T8M>] (arguing that unmodifiable smart contracts are “like programs without safety checks combined with contracts without arbitration clauses Your code will go wrong, your organization will run in ways you did not anticipate, your money will get lost, and you’ll have absolutely no recourse.”); Christopher D. Clack et al., *Smart Contract Templates: Foundations, Design Landscape, and Research Directions*, 4 (Aug. 4, 2016), <https://arxiv.org/abs/1608.00771> [<https://perma.cc/CDC7-GNQH>] (“[I]t is common for provisions of an agreement to be varied dynamically—for example, to permit a favoured client to defer paying interest Unless every possible variation is coded in advance, none of this would be possible in a tamper-proof [smart contract] system.”); Werbach & Cornell, *supra* note 11, at 17 (“Blockchain transactions are irrevocable. There is no technical means, short of undermining the integrity of the entire system, to unwind a transfer. It is, however, possible to [program] various forms of exceptions or conditions Such flexibility, however, has to be coded into the smart contract [at] the outset

necessarily lower for parties to a semantic contract, who do not have to explicitly draft the option at all—either in advance or during performance.¹⁴⁰

Performance standards present further difficulties by creating a logical gap or undefined term in the contract. A term like “commercial reasonableness” will mean different things to different parties, in different transactions, at different times. As described above, sophisticated parties can use textual tools to imbue standards with meanings that are unique to the contract’s specific transactional context.¹⁴¹ This is important given the way that blockchain relies

. . .”). Interestingly, even when commenters address the flexibility question head on, they limit their analysis to the *ex ante* inclusion of a renegotiation function. See Elaine Ou, *Smart Contracts Don’t Have to be Dumb*, BLOOMBERG VIEW (Oct. 21, 2016), <https://www.bloomberg.com/view/articles/2016-10-21/smart-contracts-don-t-have-to-be-dumb> [<https://perma.cc/X94Q-AQ5C>].

There are additional costs rooted in technical features of smart contracts. Parties to a smart contract pay a transaction fee to incentivize the network to process their contract code. In Ethereum, parties who wish to execute a smart contract must attach a bounty to the operation paid in “gas,” which is essentially a very small amount of Ether. Nodes on the Ethereum network are free to ignore proposed operations that are insufficiently funded. This supply and demand dynamic also helps police buggy or infinitely recursive code, forcing parties to internalize the cost of using valuable network resources. See DIEDRICH, *supra* note 20, at 206–10. Parties to a smart contract will have to pay gas to call its modification function or to re-execute the contract with a modified term.

¹⁴⁰ See Cimino, *supra* note 19, at 114 (noting that sole reliance on written contract terms, without any informal norms of cooperation, only lowers transaction costs when the “exchange involve[s] a low level of transactional uncertainty”).

¹⁴¹ See *supra* Part II; see also Surden, *supra* note 2, at 683 (noting that parties “may sometimes specify contract terms at a high level of generality to allow for flexibility and discretion . . . [b]ecause the computable approach involves automated comparisons . . . [it is inapt] if a scenario requires abstraction, *ex-post* flexibility in assessing facts, or the exercise of professional judgment”).

Ironically, a good demonstration of this concept comes from current events in the blockchain industry. *Ripple Labs Inc. v. R3 LRC LLC* is a lawsuit and countersuit about a breached option contract and failure to “negotiate in good faith” over details of a commercial partnership. Complaint at 7, *Ripple Labs Inc. v. R3 LRC LLC*, No. CGC-17-561205 (Cal. Super. Ct. Sept. 8, 2017). Ripple is a blockchain product that provides interbank settlement and currency exchange services. Its blockchain is supported by a currency called XRP, which serves as a medium for currency exchange and can be bought and sold by retail investors on cryptocurrency exchanges. R3 is a software consortium developing blockchain products for use by financial services companies.

As a new, disruptive entrant to the interbank payment industry, Ripple needed R3’s help in designing its product, setting up demos for potential customers, and forming relationships in the industry. R3 promised to put “XRP on the map.” *Id.* at 5. The parties entered into a Technology Partnership Agreement, in which R3 agreed to help Ripple “manag[e] the Project” and negotiate for a term sheet governing the parties’ longer-term commercial relationship. *Id.* at 7. In exchange, R3 would receive a 15% revenue share from any customers it provided, as well as an option to buy 5 billion XRP tokens with an exercise price of \$0.0085 per token until September 2019. Anna Irrera, *U.S. Blockchain Startups R3 and Ripple in Legal Battle*, REUTERS (Sept. 8, 2017), <https://www.reuters.com/article/us-r3-ripple-lawsuit/u-s-blockchain-startups-r3-and-ripple-in-legal-battle-idUSKCN1BJ27I> (last visited Oct. 12, 2017).

Since executing the Agreement, the price of XRP has skyrocketed to \$0.20 per token, making the option contract worth over \$1 billion. Ripple argues today that R3 breached the Agreement by failing to negotiate over a term sheet, and making insufficient efforts at helping to grow Ripple. Complaint at 8–9, *Ripple Labs Inc. v. R3 LRC LLC*, No. CGC-17-561205 (Cal. Super. Ct. Sept. 8, 2017). It seeks rescission of the option contract, plus damages for a variety of misrepresentation and

on decentralized technology, spreading control of a contract across many nodes.¹⁴² Storage and execution using a blockchain makes smart contracts secure and provides a natural check against bad-faith manipulation of contract terms. But this decentralization also prevents a contract from executing until nodes agree that its conditions have been satisfied. Thus, when a smart contract fails to consistently “produce[] the same output on the basis of a given input” across all participants in the system, it won’t be executed at all.¹⁴³

fraud claims. *Id.* at 14-19. R3, in its suit against Ripple, argues that the options contract lacks any unilateral termination provision and that it therefore must be enforced. *Id.* at 8-9.

Some commenters have wondered why Ripple and R3—two parties at the forefront of blockchain development—did not construct a smart contract to govern their relationship. See Elaine Ou, *R3 Should Have Used a Smart Contract*, ELAINE’S IDLE MIND (Sept. 9, 2017), <https://elaineou.com/2017/09/10/r3-should-have-used-a-smart-contract/> [<https://perma.cc/8MQT-DUUU>]. R3 in particular is a very public champion of introducing smart contracts to the financial services industry. *Id.* A smart contract would have enabled R3 to instantaneously exercise its option at its discretion, avoiding the time and expense of litigation. Presumably the two parties could have constructed a smart contract that captured the economics of their agreement, while generating publicity about the usefulness of the technology.

The fact that the parties did not illustrates this Comment’s core themes. First, the parties were transacting in an extremely volatile environment. Part of the consideration being paid was in the form of XRP tokens. Though the parties both expected the currency to appreciate based on the success of Ripple’s products, they likely had very different guesses about where it would land. Drafting a smart contract with the potential to instantaneously provide unlimited upside to one party would create enormous ex ante drafting and negotiation costs. It is almost unthinkable that Ripple would enter into such an agreement at all unless it could formally define every aspect of R3’s obligations, and then to design contingencies for every way R3 might breach.

In this case, R3’s obligations were necessarily vague. It was not bound to actually form a term sheet with Ripple—it was obligated to negotiate “in good faith.” The precise meaning of that phrase depends on the parties’ relationship and the unique context of the transaction. See *supra* notes 74–83 and accompanying text; RESTATEMENT (SECOND) OF CONTRACTS § 205 cmt. d (AM. LAW INST. 1979) (“A complete catalogue of types of bad faith is impossible, but the following . . . have been recognized in judicial decisions: evasion of the spirit of the bargain, lack of diligence and slacking off, [and] willful rendering of imperfect performance.”). Good faith is not a contractual provision that can be effectively translated into computer code.

The confluence of these conditions—inability to approximate about the ex post world of the contract, and inability to precisely and discretely define performance—makes it impossible to use a smart contract (regardless of whatever blockchain enthusiasm the parties may share).

¹⁴² Again, this argument applies to smart contracts in a fully permissionless blockchain like Ethereum. As a blockchain moves closer to the permissioned side of the spectrum—relying more on off-chain identity and traditional legal contracts—agreements can be built with more flexibility. See *supra* note 50 and accompanying text.

¹⁴³ Zhang & Hongfei, *supra* note 138; see also Hernández, *supra* note 13 (noting that a smart contract with subjective features would violate the agreement’s “security and legitimacy”).

Theoretically, parties could design a smart contract allowing them to upload volumes of information about their industry, their past relationship, the meanings of certain commercial terms, and other details. This would approximate the kind of commercial context examined by courts in settling the meaning of ambiguous terms. By including enough such information, parties could minimize the risk that nodes in the network come to different conclusions about the same underlying behavior. However, this solution would be prohibitively expensive from a transaction fee perspective—the more extensively a smart contract uses network resources, the more its parties must

Requiring that parties' "interpretive regime" be communicable and legible to any number of external agents would be prohibitively expensive from a drafting standpoint.¹⁴⁴ Such a suggestion ignores why standards exist and how they are used to manage costs of contract formation.¹⁴⁵

Smart contracts also favor anonymity. The technology's proponents worry that too much information about counterparty identity can pressure parties to accept worse terms from more powerful trading partners.¹⁴⁶ In the words of one commentator, "[t]he value add of blockchain is the whole anonymous world."¹⁴⁷ However, such anonymity also forecloses on the beneficial aspects of relationship-driven contracting.¹⁴⁸ Negotiation costs are lower when parties can imply, rather than explicitly define, shared trading customs.¹⁴⁹ And business

pay the network to execute the contract. In the Ethereum context, Diedrich notes that this supply/demand dynamic makes the network ill-suited to execute the "business logic of a . . . complex system." DIEDRICH, *supra* note 20, at 210. For an overview of how parties pay to execute their smart contracts in Ethereum, see *supra* note 139 and accompanying text.

¹⁴⁴ See *supra* notes 93–96 and accompanying text (explaining that parties can construct an "interpretive regime" molded to the unique risks of their transaction).

¹⁴⁵ Literature on non-blockchain electronic contracts does suggest some ways to approximate the flexibility provided by standards in computer code. For example, Harry Surden proposes the concept of a "threshold agreement"—a traditional semantic master agreement dictating the terms of electronically-effected transactions. Surden, *supra* note 2, at 651. This solution is confirmation of the underlying problem: absent such an agreement, there is no way to evidence "the parties' mutual understandings and goals." *Id.* Parties could instead turn to industry-defined standards and provide only minimal semantic specification in their specific agreement. See *id.* at 652–53 (explaining the efficiency of this method and listing benefits). However, the decentralized nature of blockchain makes such standardization much more difficult. See *infra* Section IV.B. Finally, Surden suggests the use of standardized contracting graphical interfaces to constrain the types of terms parties may use. Surden, *supra* note 2, at 654. This would render the Turing-completeness of Ethereum moot. See *supra* note 29 and accompanying text.

¹⁴⁶ See TAPSCOTT & TAPSCOTT, *supra* note 32, at 257–62 (noting the impact of automatic smart-contract execution on making agreement concessions); Hernández, *supra* note 13 ("Ideally you want all the information triggers to be clean and objective and not prone to a centralized party that you have to . . . trust That's part of the blockchain, having people who don't know . . . [or] trust each other [enter into transactions].") (quotation marks omitted); Szabo, *supra* note 2 (discussing the concept of privity and its relationship to anonymity in smart contracts and noting that the contents of a contract should be shared only to the extent necessary to ensure performance).

¹⁴⁷ Hernández, *supra* note 13 (noting that "the level of technological sophistication [provided by blockchain] could be overkill" when contracting with familiar parties).

¹⁴⁸ The transaction history shared by two trading partners is a strategic asset, just like factories or equipment. As their transaction history grows, the parties develop "specialized information, language, and know-how," improving communication, the quality of contract performance, and the chances of success in the market. See Jeffrey H. Dyer & Harbir Singh, *The Relational View: Cooperative Strategy and Sources of Interorganizational Competitive Advantage*, 23 ACAD. MGMT. REV. 660, 662 (1998) (discussing "three types of asset specificity: (1) site specificity, (2) physical asset specific, and (3) human asset specificity").

¹⁴⁹ In fact, research suggests that trust enables parties to progressively move from highly-defined, formal contracts to more informal arrangements over time. See Cimino, *supra* note 19, at 117 (describing a study that found that "preexisting trust was sufficiently effective at lowering

relationships provide a flexible and responsive backbone to transactions, encouraging parties to avoid litigation and preserve the promise of future trade. Empirical work in this area suggests that only parties with a strong preexisting trust would agree to the tight interconnection created by a smart contract.¹⁵⁰ This research confirms a perhaps intuitive argument that firms must be confident in their counterparty's respect for norms such as "flexibility, information exchange, and solidarity" before agreeing to connect to each other's production and payment systems using a smart contract.¹⁵¹

Next, I anticipate and respond to arguments that smart contract proponents are likely to offer. First, some of blockchain's most radical proponents envision smart contracts as reshaping the very nature of commercial organizations. I argue that even in a world full of smart contracting, parties will likely face transaction costs and pressures to increase the scale and scope of their agreements, and hence will need to deploy flexible, semantically-defined contracts. Second, I respond to claims about the open source nature of smart contracts. While open source development has benefits, it also has drawbacks in the context of agreement formation. The decentralized nature of smart contracting requires that new protocols be voluntarily adopted by users, creating uncertainty and resulting in suboptimal governance decisions. Lastly, smart contract proponents might point to decentralized dispute resolution processes already deployed by some blockchain services. I argue that these replicate the function of traditional common law courts, but without the efficiencies created by courts' use of stable interpretation rules.

B. *Smart Contracts Cannot Create a Transaction-Costless Environment*

Taken to a logical extreme, smart contracting will transform the very nature of the firm. One of the firm's core purposes is to lower transaction costs by performing tasks internally instead of contracting externally.¹⁵² But if smart contracts enable transactions to be designed cheaply, executed immediately, and performed accurately—based on precisely defined, fully rational computer code—transactions can be broken up into smaller and smaller pieces.¹⁵³ For

transaction costs of subsequent deals that parties could, essentially, afford to use a less complex, more discrete-looking contract form").

¹⁵⁰ *Id.* at 109-114 (reviewing empirical research and arguing that "firms' commitments to . . . relational norms [of flexibility, information exchange, and solidarity] probably made the transaction possible in the first place, as well as more efficient in the end").

¹⁵¹ *Id.* at 111.

¹⁵² See Oliver E. Williamson, *The Theory of the Firm as Governance Structure*, 16 J. ECON. PERSP. 171, 178 (2002) ("[T]he . . . structure [of the firm] arises mainly in the service of economizing on transaction costs.").

¹⁵³ See TAPSCOTT & TAPSCOTT, *supra* note 32, at 121 ("When aggregated, smart contracts can make firms resemble networks, rendering corporate boundaries more porous and fluid."). *But see*

example, Tapscott and Tapscott argue that smart contracts will enable companies to craft “clever, self-enforcing” agreements at “very low cost,” reducing search and coordination costs.¹⁵⁴ In this world, there is no need for long-term commercial relationships or huge deals with complex logic. Companies will “disaggregate into more effective networks.”¹⁵⁵ A producer or a service-provider will function as a kind of independent contractor, entering into rapid micro-transactions with counterparties on a one-off basis. Markets will connect anonymous sellers to anonymous buyers, and purchasing decisions will be made based on digital reputation.¹⁵⁶ As transaction costs shrink to zero, so will the need for firms. Arguing that semantic contracts are important for firms, therefore, ignores that the most beneficial effect of smart contracting is also its most revolutionary—a transformation in the nature of the firm itself.

However, this argument confuses cause and effect. Firm size and contract complexity are both responses to costs that are inherent in the formation of commercial agreements.¹⁵⁷ These costs include finding trading partners and making that search easier through advertising; designing, drafting, and negotiating agreements; and monitoring to ensure faithful performance of the agreement. The smaller the firm, the more intensely those costs are felt.¹⁵⁸ Likewise, the simpler the agreement, the more likely it will have to undergo expensive renegotiation.¹⁵⁹ Hence there is a natural economic limit on how small firms can ultimately shrink.

Smart contracts may indeed lower some of these costs, but they will raise others. Tapscott and Tapscott observe that lower costs of “monitoring [and] enforcing” a smart contract are offset by higher “up front” costs of

Levy, *supra* note 11, at 10 (“[Smart] contracts thus impose a degree of inflexibility on contractors’ relations that might short-circuit a number of alternative uses to which law is put.”).

¹⁵⁴ TAPSCOTT & TAPSCOTT, *supra* note 32, at 121, 142.

¹⁵⁵ *Id.* at 121.

¹⁵⁶ *Id.* at 122.

¹⁵⁷ Oliver D. Hart, *Incomplete Contracts and the Theory of the Firm*, 4 J.L. ECON. & ORG. 119, 123 (1988) (“[W]here transaction costs are zero . . . the parties can write a comprehensive contract. As Coase [and] Williamson . . . have emphasized, however, this is very unrealistic: in practice, transaction costs are pervasive and large . . . [P]arties will not write a contract that anticipates all the events that may occur.”). Firms may encounter diseconomies of scale beyond a certain size. Williamson observes that large, aggregated firms deploy inefficient incentives and unnecessarily intense administrative controls. TAPSCOTT & TAPSCOTT, *supra* note 32, at 121.

¹⁵⁸ See Bart Nooteboom, *Firm Size Effects on Transaction Costs*, 5 SMALL BUS. ECON. 283, 288 (1993) (discussing the “threshold costs” involved in the formation of agreements, which “arise regardless of the size of transaction” and thus affect smaller firms more than larger ones).

¹⁵⁹ See Alan Schwartz & Joel Watson, *The Law and Economics of Costly Contracting* 5-6 (John M. Olin Ctr. for Stud. L., Econ., and Pub. Pol’y Working Papers, Paper No. 264, 2001), http://digitalcommons.law.yale.edu/cgi/viewcontent.cgi?article=1004&context=lepp_papers (noting that simple agreements are often rendered “suboptimal” by the emergence of new information, requiring the parties to renegotiate).

“determining agreement terms.”¹⁶⁰ Further, these costs are likely to overlap. For example, a service contract built without the use of semantic contract standards would require *both* a highly-precise (and likely inaccurate) ex ante definition of adequate performance *and* extensive monitoring to ensure the agent’s honest, faithful performance.¹⁶¹ A contract with both features, however, would be expensive to draft and impractical to deploy. And more broadly, trading lower ex post monitoring costs for much higher ex ante negotiation costs will only make sense for the simplest agreements.

Though the size or concentration of firms may decrease in response to lower transaction costs, those costs can never disappear completely, and neither will firms. More likely, trading partners will apply smart contracts to certain pieces of their transaction, but will retain traditional semantic agreements to structure their broader relationships.¹⁶² The need to loosely but reliably define performance, and the pressure to construct larger and longer-term agreements that can change flexibly in response to unpredictable events, will exist even in a world of smart contracts.

C. Open-Source Development is Efficient in Some Contexts but Not in Contract Creation

Second, smart contract proponents might highlight the efficiency of creating agreements in an open source, collaborative way. The success of open-source software communities is well documented.¹⁶³ Proponents argue that trading partners who can’t afford sophisticated, expensive agreements—or whose transactions are too small to justify the expense—should nonetheless have access to well-made contracts.¹⁶⁴ Smart contracting may

¹⁶⁰ TAPSCOTT & TAPSCOTT, *supra* note 32, at 103.

¹⁶¹ Indeed, any agreement for a good or service not easily transformed into blockchain information, for example through an internet-of-things-enabled device, would suffer from this problem. Whenever a human agent must manually transform physical data into digital bits, there is an opportunity for dishonest behavior and therefore a need for trust.

¹⁶² Interestingly, this was the same approach advocated by the EDI commentators. *See supra* note 137 and accompanying text. Today, this is playing out in technical discussions about smart contract design. *See, e.g.*, Lim et al., *supra* note 49 (“[T]here should be a dumb contract between the parties, in the form of a ‘legal wrapper’ which sets out terms of the contract which are not deterministic and not suitable for execution through the smart contract [such as] a ‘material adverse event’ [clause].”). Permissioned blockchains rely on a similar concept to structure the relationship of network participants in a legally cognizable way. *See supra* note 50 and accompanying text.

¹⁶³ *See, e.g.*, Michal S. Gal, *Viral Open Source: Competition vs. Synergy*, 8 J. COMPETITION L. & ECON. 469, 470-72 (2012) (arguing that compared to proprietary alternatives, open-source frameworks are cheaper to use, create incentives for developers to offer their contributions for free, and result in more rapid innovation).

¹⁶⁴ *See, e.g.*, Chris DeRose, *Smart Contracts: Blockchain’s Solution for the Underserved*, AM. BANKER (Mar. 30, 2016), <https://www.americanbanker.com/opinion/smart-contracts-blockchains-solution-for-the-underserved> [<https://perma.cc/R239-PHWT>] (discussing how smart contracts may enable cheaper

help those entities replace their expensive and risky paper agreement with a tailored and autonomously-executed digital agreement.

There are two counterarguments.¹⁶⁵ First, consensus around an open-source blockchain framework doesn't exist yet, and there's enormous debate about how those standards should develop.¹⁶⁶ Open-source protocols for blockchain applications—such as those for Bitcoin—are frequently updated, but it's up to individual users to implement those updated versions. These rounds of improvements, called “forks,” spark intense disagreement in the blockchain community because they represent a majority-rule approach to changing the rules of all contracts in the system.¹⁶⁷ There is also competition among blockchain development companies serving similar functions, which

escrow services and therefore expand access to the banking system); Josh Stark, *Making Sense of Blockchain Smart Contracts*, COINDESK (June 4, 2016), <http://www.coindesk.com/making-sense-smart-contracts/> [<https://perma.cc/YJG4-UF7A>] (noting that smart contracts are a cheaper, faster alternative to legal agreements and may open up “[n]ew markets”).

¹⁶⁵ A possible third argument is that smart contracting merely replaces the expense of hiring lawyers with the expense of hiring smart contract programmers. It's not clear whether such a shift is net beneficial, especially considering the layers of added litigation expense and uncertainty that would accompany a transition to smart contracting. There is nothing about a contract regime run by programmers that's especially democratizing compared to one run by lawyers.

¹⁶⁶ See Aaron van Wirdum, *Ethereum Classic Hard Forks; Diffuses 'Difficulty Bomb'*, BITCOIN MAGAZINE (Jan. 13, 2017), <https://bitcoinmagazine.com/articles/ethereum-classic-hard-forks-diffuses-difficulty-bomb-1484350622/> [<https://perma.cc/QC3P-KDA5>] (discussing Ethereum Classic users' efforts to prevent a rapid increase in mining difficulty, which would have rendered the cryptocurrency useless). At the time of writing, Bitcoin users are also contemplating a fork to increase block size, which would allow for Bitcoin transactions to be processed more rapidly. See Kyle Torpey, *Bitcoin's Block Size Controversy is Morphing into a Debate Between Hard Forks and Soft Forks*, COINJOURNAL (Feb. 21, 2017), <http://coinjournal.net/bitcoins-block-size-controversy-morphing-debate-hard-forks-soft-forks/> [<https://perma.cc/LLC5-GZ5P>] (“For nearly the past two years, various alternatives to Bitcoin Core have attempted to increase Bitcoin's block size limit via hard-forking changes to the codebase run by nodes on the network A hard fork requires every economically-relevant Bitcoin full node (or at least nearly all of them) to upgrade to a new network.”).

¹⁶⁷ Interestingly, Ethereum Classic (also called “ETC”) was itself forked from Ethereum after the Ethereum community decided to reverse unauthorized trades. ETC users believe that permitting the reversal of undesirable transactions leads to the same political influence over money that makes fiat currency undesirable. See Aaron van Wirdum, *Ethereum Classic Community Navigates a Distinct Path to the Future*, BITCOIN MAGAZINE (Aug. 19, 2016), <https://bitcoinmagazine.com/articles/ethereum-classic-community-navigates-a-distinct-path-to-the-future-1471620464/> [<https://perma.cc/572E-CK74>] (“Ethereum Classic started off . . . as a protest movement, opposing a (perceived) bailout of Ethereum[] [T]he Ethereum Classic community [is committed to] immutability and censorship resistance [and believes Ethereum Classic embodies] the ‘code is law’ mantra, in which there is no room for forks whenever code doesn't operate [as expected].”); see also Curtis Yarvin, *The DAO As a Lesson in Decentralized Governance*, URBIT (June 24, 2016), <https://urbit.org/blog/dao/> [<https://perma.cc/5Z6D-5DMC>] (applying political theory to the Ethereum Classic fork and characterizing the majority-rules approach to Ethereum governance as a “digital banana republic”).

needlessly raises the number of service providers users must consider as they choose among many similar options.¹⁶⁸

Second, forks are vulnerable to severe collective action problems, as the majority of users may not understand an objectively better protocol, or care enough to be effectively informed, causing them to make irrational governance decisions.¹⁶⁹ Unsophisticated parties—the kinds of parties for whom smart contracting is supposed to be most beneficial—will unlikely have much sway during a fork debate. Instead, fork decisions will be captured by the most prolific smart contract users—huge, commercially sophisticated companies engaging in large numbers of routine transactions. Banks, for example, are behind the most public efforts to drive blockchain adoption.¹⁷⁰ This justifies some skepticism that smart contracting will be as radically democratic as its proponents claim.

D. *Blockchain-Based Dispute Resolution is Radically Uncertain Without Offering Any Advantage Over Traditional Contract Litigation*

Finally, it's worth noting that blockchain-enabled dispute resolution systems are already in place. These procedures allow parties to respond to disputes without the need for litigation, and proponents might therefore argue that they mimic the role of flexibility in semantic contracts. For example, OpenBazaar, a peer-to-peer marketplace similar to eBay, relies on moderators to adjudicate disputes.¹⁷¹ Buyers can include a moderator on a

¹⁶⁸ See Rob Marvin, *IBM, Microsoft Are Building Our Blockchain Future—And They're Not Afraid to Butt Heads*, PCMag (Aug. 4, 2016), <https://www.pcmag.com/article/346729/ibm-microsoft-are-building-our-blockchain-future-and-their> [<https://perma.cc/WQB7-QYNE>] (noting that participants in the blockchain community—from established firms like IBM and Microsoft to “a potpourri of consortiums, alliances, and open-source initiatives”—are members of redundant, and sometimes conflicting, development projects).

¹⁶⁹ See Yarvin, *supra* note 167 (“But after the DAO hack, how does anyone trust any contract? Arguably, Ethereum is ready to be decentralized only when users are able to make this decision rationally, and get it right. This work simply hasn't been done.”). One possible solution to this problem is to provide users with an incentive to make correct, or at least popular, governance decisions by directly tying such decisions to a cryptocurrency. See, e.g., *Governance*, TEZOS, <https://www.tezos.com/governance> (last visited Aug. 30, 2017) (describing a blockchain that permits users to propose protocol upgrades and provides rewards if those suggestions are implemented).

¹⁷⁰ See Hileman, *supra* note 16 (noting that one major smart contract consortium, R3CEV, added forty-two banks in 2016 and that sixty percent of its current participants are designated as global systemically important financial institutions by the Basel Committee on Banking Supervision).

¹⁷¹ See Sam Patterson, *How Moderators and Dispute Resolution Work in OpenBazaar*, OPENBAZAAR BLOG (Feb. 24, 2016), <https://blog.openbazaar.org/how-moderators-and-dispute-resolution-work-in-openbazaar/#:~:text=WPn6kiPyuis> [<https://perma.cc/H5J3-WNJ8>] (“[C]entralized ecommerce platforms [like eBay] . . . listen to disputes from a buyer or seller, make a decision . . . and then take action Since they control the platform directly, they have the power [to adjudicate the dispute]. This type of top-down, centralized dispute resolution on the platform isn't possible with OpenBazaar, which has no central point of control.”).

transaction, which allows for reversibility of the transaction if the moderator agrees with the complainant.¹⁷² Moderators review the parties' arguments and decide who has been wronged, triggering payment of the disputed funds.¹⁷³ The creator of Ethereum, Vitalik Buterin, has even suggested a decentralized court system to adjudicate disputes in exchange for a fee.¹⁷⁴ Such courts would be especially useful for "determin[ing] the meaning of 'reasonable.'"¹⁷⁵

However, the decentralized nature of these systems ensures that they will be essentially useless in managing the high costs of smart contracting. By shifting dispute resolution to an online system that relies on an ever-changing, unpredictable, unaccountable, and opaque group of decisionmakers, decentralized adjudication cannot generate contract "public goods" like performance standards, which emerge through the stable application of interpretation rules by courts. For example, OpenBazaar's system allows users to select their own moderators just like they would select a product to purchase on the site, based on each moderator's fees and her ratings from previous users. But each moderator is free to decide her cases based on whatever substantive principles she prefers, which may or may not be evident from her listing.¹⁷⁶ Likewise, Buterin's proposal requires that judges are "randomly selected" and then incentivized to adjudicate honestly "by the threat of a larger 'supreme court' contradicting them," resulting in forfeiture of their adjudication fee.¹⁷⁷

In these decentralized resolution systems, parties cannot know how to craft their arguments to maximize success or minimize risk. They cannot cite precedent to incorporate previous decisions, and may not even know what

¹⁷² *Id.*

¹⁷³ *Id.*

¹⁷⁴ See Vitalik Buterin (vbuterin), *Decentralized Court*, REDDIT (Apr. 16, 2016), https://www.reddit.com/r/ethereum/comments/4gigydl/decentralized_court/ [<https://perma.cc/X9QC-3DRV>] (proposing a "decentralized court" "by which a user could ask a question, expressed in the form of English text, and have a decentralized mechanism . . . determine the answer, and then send a callback and a log to the user who asked the question"). Another proposal is contained in TAPSCOTT & TAPSCOTT, *supra* note 32, at 104 (describing a system for designating in advance a "neutral, disinterested third-party arbitrator" to enable parties to complete transactions using smart contracts).

¹⁷⁵ See Buterin, *supra* note 176.

¹⁷⁶ See *How to Choose a Good Moderator on OpenBazaar*, OPENBAZAAR BLOG (Dec. 1, 2016), <https://blog.openbazaar.org/how-to-choose-a-good-moderator-on-openbazaar/> [<https://perma.cc/RM2V-WR35>]. For a listing of OpenBazaar moderators, see *Moderators*, DUO, <https://duosear.ch/moderators> (last visited Aug. 30, 2017). A representative OpenBazaar moderator is @bitcoinmitchell, who charges a two percent moderation fee and is trusted by fourteen users. See @bitcoinmitchell, DUO, <https://duosear.ch/@bitcoinmitchell> (last visited Aug. 30, 2017). The user's entire explanation of his moderation process is only four sentences long: "In the case of a dispute, both sides will present their evidence. Reasonable effort will be made towards a mutually agreed resolution. If no resolution can be agreed upon then the evidence will be weighed and a decision will be made. If it is not clear whom the rightful party is then funds will be split based on the assessment of the moderator." *Id.*

¹⁷⁷ Buterin, *supra* note 174.

those previous decisions were. They cannot deploy performance standards because there's no way to restrict the range of review used by randomly-selected courts, which may or may not respect the wording of a particular merger clause or a preamble that restricts relevant commercial practice to a specific industry. As a result, decentralized adjudication will grow more resource-intensive over time as parties attempt, and inevitably fail, to define every contingency *ex ante* with the exacting rigor of computer code. In short, without the tools created for traditional contracts by traditional courts, parties will have to argue every dispute from scratch, and without any idea about how such disputes will be analyzed.¹⁷⁸

CONCLUSION

There is no contract technology that fits every possible transaction. Instead, firms blend formal governance mechanisms with informal modifications, crafting commercial relationships that can withstand the unique pressures facing their business and industry. Smart contracts will offer meaningful improvements to contracting under certain conditions—for example, where there is low uncertainty or where performance monitoring would otherwise be especially expensive. Perhaps firms will deploy smart contracts in certain areas of their business or to manage a defined category of routine transactions. But we know today that firms consider contractual flexibility to be a crucial strategic issue.¹⁷⁹ Smart contracts that fail to offer semantic and enforcement flexibility will be useful in a very limited set of circumstances.

The impacts go beyond transaction costs. Fraudulent and unconscionable contract terms, traditionally policed by courts, would likely proliferate as “code-savvy parties” take advantage of the “code-naive.”¹⁸⁰ Decentralized

¹⁷⁸ See Werbach & Cornell, *supra* note 11, at 32 (assessing whether smart contracts “offer[] the possibility of making courts essentially obsolete—surpassed by mechanisms that can enforce obligations . . . with greater efficiency and customization”). A blockchain adjudication system might be able to capture the benefits provided by traditional courts. For example, it could deploy a stable pool of judges, require that opinions be published, and design incentives to reward decision convergence. All smart contracts executed in the system would be subject to redrafting or rescission by the system’s judges. This system would be an extreme example of permissioned blockchain and thus subject to the same vehement criticism by blockchain purists, such as concerns about security and corruption.

At the same time, the more a decentralized system comes to look like a traditional court, the less advantage there is to smart contracts in the first place. Indeed, OpenBazaar’s dispute resolution system and traditional common-law courts are conceptually quite similar, except that the latter has had centuries to mature.

¹⁷⁹ See Cimino, *supra* note 19, at 111-115 (“Usually we think that express terms set out the parties’ economic expectations, while background relational expectations are merely informal grease for the wheel. But . . . research suggests that contractors see relational expectations as *economic* expectations.”).

¹⁸⁰ Marino & Juels, *supra* note 138, at 157 (claiming that “code-savvy parties . . . defraud[ing] or forc[ing] unconscionable terms on code-naïve parties” would constitute “grounds for reformation”).

blockchain adjudicators would be unable to efficiently create doctrine around such fact-intensive questions. And though some proponents have envisioned smart contracts with special intervention functions for traditional courts, they presume that traditional judges will interpret smart contracts using traditional contract doctrine.¹⁸¹ Code fails to contain the interpretive richness conveyed by semantic language, and so intervening courts would be forced to essentially rebuild entire agreements from scratch. This is likely intolerable to both code-savvy and code-naive parties to a smart contract.

These tradeoffs suggest that technology cannot replace what is fundamentally a human activity. Smart contracting certainly proposes exciting new changes to the way transactions might take place, and presents a meaningful step forward from the days of EDI. But a full-scale smart contracting revolution would introduce costs far more extreme and intractable than the ones it seeks to solve. Proponents who argue for a complete replacement of semantic contracts underestimate the power of fluid human behavior and judgment in the contracting process. The flexibility of semantic contracts is a feature, not a bug.

¹⁸¹ *E.g., id.* at 155 (“Few feel confident reading ‘legalese’; even fewer feel confident reading code. In light of this, our first standard is a familiar one: when there is unilateral mistake—or when any of the other bases for Rescission by Court exist—and a court orders a smart contract rescinded, auto-performance must cease.”).

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