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ARTICLE

The Social Cost of Blockchain: Externalities, Allocation of Property Rights, and the Role of the Law

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Abstract

In the past decade, the legal and economic literature on blockchain technology and its applications has flourished. This new technology holds great promise for enhancing the efficiency of contracting. Building on the classic Coase theorem, blockchain as a decentralised mechanism of decision-making should be superior to centralised regulation, possibly yielding substantial efficiency gains. Notably, it also has the potential to improve the allocation of property rights and reduce transaction costs.

However, many of these enthusiastic views about what blockchain technology may bring are overblown. This article demonstrates that blockchain creates a variety of new externalities, which cannot be addressed by the decentralised actors using it. The most obvious of them is the environmental externality stemming from the energy-intensive mining process. In addition, more immediate externalities emerge, for example through the operational and legal risks of being part of a blockchain transaction, which are particularly evident in the crypto economy. Moreover, issues surrounding blockchain governance may exacerbate these challenges.

In conclusion, we propose several regulatory strategies to mitigate these shortcomings and harness the full potential of blockchain technology.

Keywords: blockchain technology; Coase theorem; social cost

JEL Codes: K11; K22; K29

I. Introduction

Over the past decade, there has been an unprecedented surge in interest and debate surrounding blockchain and distributed ledger technology (DLT) across various sectors. This discourse involves diverse stakeholders, from tech disruptors leveraging blockchain applications to traditional players adapting to its disruptive potential. As regulators and academics grapple with the impacts this emerging technology, questions regarding its regulatory framework have become prominent.

The lively academic debate has evolved across several disciplines.[1] This article contributes to the existing literature by adopting an interdisciplinary perspective from

[1] See Satoshi Nakamoto, "Bitcoin: A peer-to-peer electronic cash system" available at <https://bitcoin.org/en/bitcoin-paper> accessed 22 March 2024. After the Bitcoin Whitepaper, the technology took off and so did the policy debate and the academic literature. The latter has developed along many different dimensions. Beyond the

law and economics, focusing on the role of the law in addressing social costs arising from blockchain activities. More specifically, this article unpacks the role of the law when these activities generate negative effects on third parties or, in other words, when these activities entail social costs.

We approach the interaction between the law and blockchain technology through the classic framework developed by Professor Ronald H. Coase in 1960.[2] Simply put, Coase posits that decentralised market-based approaches can outperform centralised regulatory interventions (such as taxes or regulation) under certain conditions.[3] This simple yet elegant idea became known as the "Coase theorem."[4] Coase was awarded the Nobel Memorial Prize in Economic Sciences in 1991 "for [Coase's] discovery and clarification of the significance of transaction costs and property rights for the institutional structure and functioning of the economy." The Coase theorem has since been influential in the analysis of virtually any legal domain.[5] Our paper seeks to extend this analysis to blockchain technology, examining how well it aligns with Coasean assumptions and the role of the law in maximising its potential.[6]

We argue in this paper that while blockchain technology holds promise in terms of increasing the efficiency of entitlement allocation, it does not always adhere to Coasean assumptions. Accordingly, we contend that the law plays an indispensable role in enabling blockchain to realise its full potential in entitlement allocation. Thus, we show that the potential of blockchain technology in allocating entitlements efficiently can only be fully unleashed with the support of formal legal institutions. In this regard, the law is not only a tool to limit the possible abuses or misbehaviours of parties acting in the crypto economy, but it also represents an essential and enabling feature of such an economy.[7]

The main contribution of this paper is theoretical. We propose a new novel framework to analyse the relationship of blockchain vis-à-vis the law, enriching the traditional approach through the lens of the Coase theorem. This goes beyond the analysis of one single piece of legislation. Rather, it provides future commentators with tools to analyse specific elements of blockchain regulation or to design new ones.

computer science and cryptography literature, huge bodies of literature are developed in, among others, law, economics, finance, management, accounting, environmental studies and so forth. For a broad overview of the literature, see Anjee Gorkhali, Ling Li and Asim Shrestha, "Blockchain: A Literature Review" (2020) 7 Journal of Management Analytics 321.

[2] Ronald H Coase, "The Problem of Social Cost" (1960) 3 Journal of Law and Economics 1.

[3] Arguing against the so-called "Pigouvian approach." Arthur Pigou, *The Economics of Welfare* (London, MacMillan and Co 1920). The emphasis on the centralised versus decentralised feature of different approaches to negative externalities is added and foreshadows the appeal of Coase's framework to discuss the interplay between the blockchain and the law.

[4] Coase never formulated a theorem and was always very reluctant to do so. What is called the "Coase theorem" was formulated by Stigler based on the seminal work of Coase 1960 (n 2). See George J Stigler, *The Theory of Price* (4th edn, New York, The McMillan Company 1966) 113.

[5] For a comprehensive survey, see Steven G Medema, "The Coase Theorem at Sixty" (2020) 58 Journal of Economic Literature 1045.

[6] Few limited and unsystematic attempts to use Coase for explaining the interplay between the blockchain technology and the legal framework were already proposed. See Philipp Paech, "The Governance of Blockchain Financial Networks" (2017) 80 Modern Law Review 1073; Roee Sarel, "Property Rights in Cryptocurrencies: A Law and Economics Perspective" (2020) 22 North Carolina Journal of Law & Technology 389.

[7] The present article looks at externalities in the blockchain from a general, theoretical perspective. This allows us to provide a general understanding of the role of the law vis-à-vis blockchain applications. Practically, different blockchain application brings about different externalities, both in form and intensity. Intuitively, bilateral smart contracts transferring tokens upon on-chain contingencies and the sale of real-world assets (RWA) bring about very different potential externalities. A granular analysis of the specific externalities in specific cases is beyond the scope of this analysis. However, the theoretical framework we propose can inform further research on specific externalities of various blockchain application and the specific role of the law to unleash the full (social) potential of that blockchain application.

The article is structured as follows: Part II establishes the connection between blockchain technology and the Coase theorem; Part III re-evaluates the promise of blockchain in terms of entitlement allocation; Part IV examines the social costs inherent in the blockchain economy and explains why on-chain solutions may fall short in addressing them; Part V, building on the analytical framework outlined in Part IV, discusses the pivotal role of the law in unlocking the full potential of blockchain technology; and Part VI concludes.

II. Coase and blockchain

The basic Coasean framework represents the idea blueprint to analyse the economic functioning of blockchain technology and the role of the law therein. In fact, blockchain aims to efficiently allocate entitlements through a decentralised process. In the Coasean framework, this guarantees superior outcomes compared to centralised public policies when it comes to handling externalities. Crucially, this holds true only under the assumptions of very low transaction costs and a clear initial allocation of property rights. As long as these assumptions hold, market participants may exchange property rights, ensuring that these entitlements are allocated to the party who values them the most, thereby internalising the externalities. In this scenario, the law is almost irrelevant, as it merely enforces agreements and provides for an initial allocation of property rights.[8] Specifically, legal arrangements are irrelevant for social welfare and have only an allocative effect.

However, in his speech upon receiving his Nobel Prize, Coase highlighted that the main legacy of the theorem would be to provide a framework for analysis in a world where transaction costs are higher and where the solution to the problem of social cost largely depends on the legal system.[9] In this more refined scenario depicting more realistically the modern economic system, the role of the law can be either enabling or essential.[10]

The law may play an *enabling* role in lowering transaction costs and in clearly allocating property rights.[11] This means that pure market transactions would be unable to allocate rights efficiently, either because transaction costs would be prohibitive or because of uncertainty regarding the initial allocation of property rights. In turn, this would result in social costs that private parties could not internalise. Of note, the law can improve the ability of private parties to contract around their entitlement, enabling them to reach efficient outcomes and privately internalise potential social costs.

In contrast, if transaction costs are prohibitively high, the role of the law in initially allocating property rights becomes *essential*, as parties would not otherwise be able to contract around such an initial allocation. Therefore, the law not only matters with regard to how wealth is allocated, but also in terms of the amount of wealth that can be generated. In other terms, the law not only determines how to split the pie, but it also dictates how big the pie is going to be.[12]

[8] In such an idealised framework, any transfer is Pareto optimal. Thus, strictly speaking, the law is not even relevant for enforcement. In this extreme scenario, the law should only avoid to prevent the efficient transfer from happening.

[9] Ronald H Coase, "The Institutional Structure of Production" (12 September 1991) available at <https://www.nobelprize.org/prizes/economic-sciences/1991/coase/lecture/> accessed 22 March 2024.

[10] We borrow the terminology from professors Hansmann and Kraakman. Henry Hansmann and Reinier Kraakman, "The Essential Role of Organizational Law" (2000) 110 Yale LJ 387, 438.

[11] Coase, "The Problem of Social Cost" (n 2) 853. For a recent formal discussion of the matter, see Carmine Guerriero, "Property Rights, Transaction Costs, and the Limits of the Market" (2023) 24 Economics of Governance 143.

[12] Francesco Parisi, "Coase Theorem," *New Palgrave Dictionary of Economics* (London, Palgrave McMillan 2008) 859. For a broader discussion on the economic value of law, see Katharina Pistor, "The Value of Law" (2020) 49 Theory and Society 165.

Translating Coase's reasoning and adapting it to the technological characteristics of blockchain, we can analyse instances in which parties, thanks to blockchain, can allocate entitlements efficiently. This directly follows from the fact that the assumptions of the Coase theorem mimic the basic premises of blockchain. The entitlements are exchanged at negligible transaction costs, and property rights are clearly and perfectly allocated by design in a decentralised, self-enforceable, and immutable ledger. This position, at least implicitly, is supported by many proponents of the various blockchain technology applications.[13]

Should this hold true in all instances, the law would be largely irrelevant, if not detrimental. Instead, the code would be law, and such code could internalise negative externalities.[14]

The original cypherpunk idea of an environment completely detached from, and alternative to, the traditional legal system is fading, mainly courtesy of several scandals to have emerged in recent years. Nonetheless, the opinion that the legal system represents an impediment to the full deployment of blockchain's potential is still widespread.[15] Consequently, according to this view, blockchain-specific regulation should shield blockchain activities from the interference of the legal system rather than addressing the specific social costs generated by the crypto economy.[16]

Our approach enables us to answer fundamental questions regarding the understanding of the interplay between blockchain and legal institutions. First, can blockchain technology function as a decentralised technology that allows for the efficient allocation of entitlements? If, as this article shows, the answer to this question is negative, and given the specific characteristics of blockchain technology, two follow-up normative questions arise. First, what should the role of the law be vis-à-vis blockchain? And, second, what legal tools are desirable to achieve socially efficient results?

This marks an innovative step in the field, as the analysis in the current literature too often does little more than reveal the authors' priors. On the one hand, the blockchain enthusiasts within the existing literature take for granted that blockchain is a desirable innovation and focus on the legal and economic issues that must be ironed out to unlock its full potential.[17] On the other hand, blockchain sceptics challenge the desirability of fully unleashing the potential of blockchain technology,

[13] Sece, for instance, Sinclair Davidson, Primavera De Filippi and Jason Potts, "Economics of Blockchain" (2016) Working Paper available at <https://ssrn.com/abstract=2744751> accessed 22 March 2024.

[14] Borrowing from a famous expression from Lawrence Lessig, "Code Is Law. On Liberty in Cyberspace" (Cambridge, MA, Harvard Magazine 2000) p. 1.

[15] Among many possible examples, a paradigmatic one is offered in a statement by Sam Bankman-Fried during a congressional hearing in 2021. Bankman-Fried stated that "an appropriate policy framework for market regulation of crypto assets should remain market-structure neutral and expressly allow non-intermediated markets." See Committee on Financial Services, "Digital Assets and the Future of Finance: Understanding the Challenges and Benefits of Financial Innovation in the United States" (House of Representatives 2021) Congressional Hearings 117–163, 107 available at <https://www.govinfo.gov/app/details/CHRG-117hhrg46302/CHRG-117hhrg46302/summary> accessed 22 March 2024.

[16] The latest example of this approach is offered by the debate around the liability regime applicable to a Decentralised Autonomous Organization (DAO). Several court decisions are sanctioning the unlimited liability of DAO token holders, categorising these as unlimited partnerships. See, for instance, United States District Court in *Sarcuni v bZx DAO*, No 22-cv-0618 (S.D. Cal. 27 March 2023). Beyond the merit of the claim, these decisions are not seen as a natural consequence of the rule of law holding parties liable for their actions according to applicable legislation. Rather, this is regarded as an undesirable side-effect of outdated legal principles. For a wider discussion on this point and on the legal and economic aspects of DAO, see Oscar Borgogno and Edoardo Martino, "Decentralised Autonomous Organisations: Targeting the Potential beyond the Hype" (2024) Law, Innovation and Technology 1.

[17] Among many others, see David Yermack, "Corporate Governance and Blockchains" (2017) 21 Review of Finance 7. For a particularly sharp critique of the enthusiastic takes on Blockchain, especially in its relationship with the legal system, see Edmund Schuster, "Cloud Crypto Land" (2021) 84 The Modern Law Review 974.

highlighting possible risks as well as at the substantial legal and economic hurdles that could impede its widespread adoption.[18] Sensible arguments have been presented from both perspectives. However, a comprehensive law and economics framework for analysis of the issue is absent.[19]

III. The promises of blockchain

Blockchain is a technical solution for managing data in a distributed infrastructure without a central intermediary in a traceable and tamper-proof manner. It promises to allow verification of transactions (for example, in payment transactions with cryptocurrencies) trustingly and transparently without the need for a central authority. In essence, blockchain technology therefore aims to create an environment where strangers can safely interact bearing minimal transaction costs.[20] Crucially, the consensus-based record validation that is inherent in the technology is able to eliminate the need for a trusted intermediary which makes it particularly attractive for applications such as the management of supply chains and related interactions.[21] In addition, the "property" of crypto-assets is immutably recorded on the ledger after the nodes reach consensus.[22] Beyond the technical details as to how blockchain works, it is clear that the ultimate promise of the technology is to allow all parties to transact freely at minimal transaction costs, exchanging entitlements until these are allocated to whoever values them the most.[23]

In other words, blockchain – and the algorithmic consensus protocol proofing the validity of the transaction happening there – would represent an institutional setting that largely satisfies the assumptions on which the Coase theorem is built. Implicitly, or even explicitly, the most enthusiastic supporters of blockchain argue that code is enough to ensure the efficiency and fairness of a transaction. In other words, code is law.[24]

If these promises hold true, the role of the traditional legal system becomes negligible, as there would be no need for institutions such as trusted intermediaries that allocate

[18] Fatjon Kaja, Edoardo D Martino and Alessio M Pacces, "FinTech and the Law and Economics of Disintermediation" in Iris Chiu and Gudula Deipenbrock (eds), *Routledge Handbook of Financial Technology and Law* (London, Routledge 2021).

[19] Some authors have discussed specific aspects using a law and economics perspective. See, for instance Massimiliano Vatiero, "Smart Contracts vs Incomplete Contracts: A Transaction Cost Economics Viewpoint" (2022) 46 Computer Law & Security Review 105710; Benito Arruñada and Luis Garicano, "Blockchain: The Birth of Decentralized Governance" Pompeu Fabra University, Economics and Business Working Paper Series no 1608/2018 available at <https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3160070> accessed 22 March 2024.

[20] Davidson, De Filippi and Potts (n 13) 9.

[21] Christoph G. Schmidt and Stephan M. Wagner, "Blockchain and Supply Chain Relations: A Transaction Cost Theory Perspective" (2019) 25 Journal of Purchasing and Supply Management 100552; Weifeng Chen, "A Transaction Cost Perspective on Blockchain Governance in Global Calue Chains" (2022) 31 Strategic Change 75.

[22] Assets that are cryptographically secured digital representations of value or contractual rights that use some type of distributed ledger technology (DLT) and can be transferred, stored or traded electronically. See, for instance, Financial Conduct Authority, "Cryptoassets: Our Work" available at <https://www.fca.org.uk/firms/cryptoassets> accessed 22 March 2024. In this context, we use here property in a non-technical way, indicating the possibility control the destiny of the crypto assets encoded in the chain. On the more technical definition of property rights, properly defined, in the blockchain see Sarel (n 6); Jason Grant Allen, "Cryptoassets in Private Law" in Iris HY Chiu and Gudula Deipenbrock (eds), *Routledge Handbook of Financial Technology and Law* (London, Routledge 2021) 309.

[23] Some empirical evidence shows how blockchain decreases transaction cost in foreign exchanges. See Thomas Kim, "On the Transaction Cost of Bitcoin" (2017) 23 Finance Research Letters 300.

[24] On the promises of the blockchain technology, see Samer Hassan and Primavera De Filippi, "The Expansion of Algorithmic Governance: From Code is Law to Law is Code" Field Actions Science Reports, Special Issue 17/2017, available at <http://journals.openedition.org/factsreports/4518> accessed 22 March 2024.

property rights, record transactions in a centralised ledger, or enforce promises. Everything, so its proponents argue, can be done more efficiently on blockchain.

Notably, in a world where the assumptions of no transaction costs and clear allocation of entitlements are satisfied, the law would have neither an essential nor an enabling role. This contrasts with the off-chain world where the law typically retains an enabling role. In blockchain, holding the assumptions, the initial allocation of entitlements and the enforcement of transactions can be better achieved using the technological design of the given blockchain itself.[25]

As noted above, the extreme claims of blockchain being a radical alternative to traditional legal systems are fading. However, a recurrent argument posits that traditional legal systems intrude in blockchain activities, generating unwanted interactions and undermining the potential of the technology. In this regard, the debate in the aftermath of the FTX collapse represents a telling case. Many commentators, especially those active in the blockchain economy, claimed that the FTX collapse could not be categorised as a crypto failure as it was driven by elements of residual financial centralisation.[26] Accordingly, they claim, the way to "save" the crypto industry would be to go back to its roots, leveraging its alternative nature compared to traditional finance. In addition, and differently from the early cypherpunk claim, blockchain activities would have to be sanctioned by law.[27]

The factual recognition of the role of residual centralisation in the FTX collapse has some merit. By and large, FTX can be understood as a rather traditional Ponzi construction.[28] However, that of itself does not justify jumping to the conclusion that pure blockchain activities, fulfilling their promises and being sanctioned by law, would have averted such a collapse. In fact, looking at the matter through a Coasean lens, it remains unclear why the parties were unable to contract around these social costs, thereby internalising them. One possible and sensible interpretation is that pure blockchain solutions, such as the use of non-custodial wallets and decentralised exchanges, imply significant transaction costs, preventing the given blockchain from achieving the efficient allocation of entitlements.[29]

To gain a firmer grasp of this more nuanced approach, we focus on four blockchain characteristics: decentralisation; self-enforceability; immutability; and the need for minimal trust. These characteristics are essential to the creation of a Coasean environment, where decentralised exchanges generate social efficiency.

Immutability refers to the property of data stored on a blockchain that cannot be changed or deleted once recorded and confirmed on the network. This is supposed to ensure a clear and tamper-resistant allocation of property rights by providing an unchangeable and trustable ledger of ownership and transactions. To its supporters, this has the potential to reduce disputes, increase trust, and simplify the management of property rights in various domains. The concept of immutability is reinforced through decentralised consensus protocols, such as Proof of Work (PoW) and Proof of Stake (PoS),

[25] Aaron Wright and Primavera De Filippi, "Decentralized Blockchain Technology and the Rise of Lex Cryptographia" (2015) Working Paper available at <https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2580664> accessed 22 March 2024.

[26] Illia Polosukhin, "Crypto Didn't Fail FTX; People Did" *CoinDesk* (22 November 2022) available at <https://www.coindesk.com/layer2/2022/11/22/crypto-didnt-fail-ftx-people-did/> accessed 22 March 2024.

[27] Mark Edwin Burge, "After FTX: Can the Original Bitcoin Use Case Be Saved?" (2023) 72 University of Kansas Law Review 1.

[28] Thomas Conlon, Shaen Corbet and Yang Hu, "The Collapse of the FTX Exchange: The End of Cryptocurrency's Age of Innocence" (2023) The British Accounting Review 101277, 11. See also Joshua Oliver, "What Crypto (Still) Gets Wrong" *Financial Times* (London, 16 March 2024), Life & Arts 1.

[29] Sirio Aramonte, Wenqian Huang and Andreas Schrimpf, "DeFi Risks and the Decentralisation Illusion" (2021) BIS Quarterly Review 21, 26.

adding another layer of security and trust to the system. The other listed characteristics concern minimising transaction costs: the lack of a needed central trusted party allows for costly intermediaries, such as banks and other financial institutions, to be substituted. The absence of pre-established trust among parties and the self-enforceability of promises made in a blockchain decrease both ex-ante and ex-post transaction costs.

However, Coase himself warned of possible Nirvana fallacies here.[30] In his speech upon being awarded his Nobel Prize, Coase discussed stock exchanges, which are often seen as examples of near-perfect competition. Looking closely at these marketplaces, one realises how there are several legal layers determining various aspects such as what can be exchanged, who can participate in the exchange, and the rules for clearing and settlement.[31] Similarly, blockchain, the consensus protocols, and the various applications characterising the crypto economy also rely on several technological layers. In our analysis of blockchain-specific social costs, we discuss four key layers outlined below.

1) The **technological characteristics** of blockchain, namely decentralisation, self-enforcement, immutability, and the need for minimal trust, all of which are key for the assumptions of the Coase theorem to hold.
2) The **inherently transactional nature** of blockchain: the economic activities carried out in blockchain are, by design, transactional. The simplest illustration thereof is investing in cryptocurrencies, such as Bitcoin, while acquiring/selling non-fungible tokens (NFTs) or governance tokens, or entering into smart contracts are other prevalent examples.
3) The **objects of the transaction** (eg, crypto-assets), differentiating between crypto-assets endogenously created within a blockchain (eg, cryptocurrencies) and crypto-assets that are exogeneous representations of a different entitlement (eg, a token representing a property right on real estate or a token representing a voting right in a decentralised autonomous organisation (DAO)).
4) The **key players** needed for a blockchain, and the transactions therein, to work. Specifically, these include: custodians and crypto exchanges; issuers of derivative crypto tokens (in Ethereum and similar protocols); coders (of smart contracts); significant miners; and core developers. This layer is crucial as it starts to show how (new and old) intermediaries are necessary for a blockchain to function as an allocative technology. Going back to our Coasean framework, these intermediaries entail transaction costs, may cause ambiguity on the allocation of property rights, and could generate externalities.

The next section aims to decompose the blockchain ecosystem, looking at the various institutional components that make blockchain transactions possible. Doing so allows us to critically review the extent to which blockchain represents a Coasean environment.

IV. The social cost of blockchain

Looking at the overall blockchain ecosystem, one quickly appreciates that the promises of blockchain are far from being honoured.

[30] Borrowing from a famous expression in Harold Demsetz, "Information and Efficiency: Another Viewpoint" (1969) 12 The Journal of Law and Economics 1. ("The view that now pervades much public policy economics implicitly presents the relevant choice as between an ideal norm and an existing 'imperfect' institutional arrangement. This nirvana approach differs considerably from a comparative institution approach in which the relevant choice is between alternative real institutional arrangements").

[31] Coase, "The Institutional Structure of Production" (n 9).

First, it would be delusional to believe that blockchain provides the possibility of writing perfectly state-contingent contracts through which parties can privately address the problem of social cost. In other words, blockchain itself is unable to reduce or even eliminate externalities. In reality, there are new externalities created by this technology. To illustrate that point, blockchain, specifically with its PoW consensus mechanism, can create a range of *environmental* externalities primarily due to its energy-intensive nature. For example, PoW blockchains require miners to solve complex cryptographic puzzles through a trial-and-error process. This undertaking demands a substantial amount of computational power, which, in turn, requires a significant amount of energy. Moreover, miners use powerful hardware and compete to be the first to solve puzzles and add a new block to the blockchain. This competition drives up energy consumption as miners continually increase their computational power to gain a competitive edge. Beyond pure energy consumption, blockchain is also associated with the depletion of natural resources, a high carbon footprint, and the creation of a significant amount of e-waste as old hardware quickly becomes obsolete.

The alternative PoS validation methodology aims to cure the excessive environmental externalities inherent to mining.[32] However, it is also prone to weaknesses, especially in terms of entitlement allocation. First, PoS protocols are less resilient than PoW alternatives in terms of tamper-proofness of validation.[33] Second, and relatedly, validators with large "stakable" holdings can have a sizeable influence in transaction verification. This is yet another form of residual power concentration in blockchain technology.[34] Third, staking holdings implies reducing the overall liquidity of the market. This is contractually accounted for, with additional yields offered to those who are willing to stake their tokens. However, in times of stress, illiquidity generates further systemic externalities which are not captured by *inter partes* remuneration for staking.[35]

Decentralisation is another revealing example in this regard. If it is true that decentralised consensus protocols allow the ledger to be distributed among several different nodes throughout the world, it is also true that this does not equate to the elimination of intermediaries and the related transaction costs.[36] The blockchain-related concept of decentralisation concerns the computational possibility of validating transactions in a peer-to-peer environment, obviating the Byzantine general problem. The direct transposition of this concept into the realm of law and economics is unwarranted and potentially generates the problem of things being lost in translation.[37]

This ambiguity in the meaning of "decentralisation" is evident if one considers the ways in which transactions are validated. Under PoW validation, a certain amount of computing power must be exercised by miners. As the main blockchains currently used are designed as computationally intensive protocols, the mining power tends to be concentrated in the

[32] For the differences between proof-of-work and proof-of-stake protocols, see Tuyet Duong and Others, "Twinscoin: A Cryptocurrency via Proof-of-Work and Proof-of-Stake" (Proceedings of the 2nd ACM Workshop on Blockchains, Cryptocurrencies, and Contracts, 2018).

[33] Ulysse Pavloff, Yackolley Amoussou-Guenou and Sara Tucci-Piergiovanni, "Ethereum Proof-of-Stake under Scrutiny" (Proceedings of the 38th ACM/SIGAPP Symposium on Applied Computing, 2023).

[34] See on this below, text to n 52.

[35] This is a well-known mechanism in finance. For a formalisation of the argument, see Arvind Krishnamurthy, "Amplification Mechanisms in Liquidity Crises" (2010) 2 American Economic Journal: Macroeconomics 1.

[36] Oliver (n 28).

[37] Aramonte, Huang and Schrimpf (n 29). On the specific elements of residual centralisation of DeFI application, especially looking at Layer 2 and Layer 3 blockchain applications, see Katrin Schuler, Ann Sofie Cloots and Fabian Schär, "On Defi and On-Chain CeFi: How (Not) to Regulate Decentralized Finance" (2024) 10 Journal of Financial Regulation 213.

hands of a few powerful miners that can be effectively seen as new intermediaries operating between the transacting parties.[38]

Beyond validation, the vast majority of crypto-assets are not simply left in the blockchain but are deposited in user-friendly wallets. The latter, not being part of a blockchain, are easier to hack, which has been a consistent problem over the last decade, sometimes to a spectacular degree.[39] Needless to say, crypto wallets and crypto exchanges are picked by the holders of crypto-assets based on their contractual conditions, as well as on the trust that crypto-asset holders have in different wallets or exchanges.

Ultimately, consensus protocols are written by coders. The reliability, quality, and honesty of code cannot be simply assumed, especially at a prospective stage where the technology is being upscaled and where many users will be fully ignorant in terms of cryptography and algorithms. This is the case even more when considering strings of code that can run on "naked blockchain," such as smart contracts.[40]

There are numerous other such examples, and one could also consider other problematic characteristics of blockchain. However, the gist of the argument here is that blockchain, at least at its current stage of technological development, merely changes the intermediaries involved, and the need to trust these new intermediaries persists. This line of reasoning has been reinforced by the several scandals in the blockchain ecosystem known collectively as the so-called "crypto winter."[41]

Blockchain does not eliminate transaction costs nor does it get rid of intermediaries. Instead, it reshuffles them, and often in a less transparent way. If transaction costs are shaken up, one could wonder whether blockchain is able to privately internalise the social costs (externalities) it generates.

To be fair, we are not claiming that blockchain technology cannot solve certain societal problems or improve existing market infrastructure, as some of its critics have argued after the recent scandals.[42] Rather, our point is that the initial and continuing enthusiasm for blockchain as well as the current scepticism toward it are both misplaced. We contend that blockchain can unleash its potential as long as it is backed by the law and is intertwined with the law. According to this view, code is not law nor does it represent an alternative to legal norms. Instead, it is simply a way of entering into transactions. At the same time, the law retains its enabling and essential role.

Decomposing the market structure and transaction phases elucidates this very point.[43] Indeed, markets should be understood as multi-layered infrastructures allowing parties to

[38] This phenomenon can also lead to a centralisation of mining operations in regions with cheap electricity, which may not always have sustainable or environmentally-friendly energy sources. See Liana Badea and Mariana Claudia Mungiu-Pupăzan, "The Economic and Environmental Impact of Bitcoin" (2021) 9 IEEE Access 48091.

[39] In 2014, the largest crypto wallet and crypto exchange in the world, MtGox filed for bankruptcy after it was hacked. See Matthew Beedham, "A Brief History of Mt. Gox, the $3B Bitcoin Tragedy That Just Won't End" (*The Next Web*, 19 March 2019) available at <https://thenextweb.com/news/a-brief-history-of-mt-gox-the-3b-bitcoin-tragedy-that-just-wont-end> accessed 22 March 2024.

[40] The DAO (Decentralised Autonomous Organization) was a smart contract running in Ethereum. It raised finance through the issuance of DAO tokens, exchanged for ethers. The DAO should have acter as a venture capital entity where the participants would have voted on the projects to undertake. The DAO was hacked before the start of its operation. This event generated a hard-fork where the community split between Ether and Ether Classic. See David Siegel, "Understanding the DAO Attack" *Coin Desk* (13 January 2023) available at <https://www.coindesk.com/learn/understanding-the-dao-attack/> accessed 22 March 2024.

[41] Douglas W Arner and Others, "The Financialization of Crypto: Designing an international Regulatory Consensus" (2024) 53 Computer Law & Security Review 105970. See also Gary B Gorton and Jeffery Zhang, "Bank Runs During Crypto Winter" Harvard Business Law Review, forthcoming.

[42] See, for instance, Hilary J Allen, "Regulating Fintech: A Harm Focused Approach" (2024) 52 Computer Law & Security Review 105910. For an overview, see Joshua Ellul, "Blockchain Is Dead! Long Live Blockchain!" (2021) 4 (1) The Journal of The British Blockchain Association 1.

[43] Special thanks to Simon Gleeson for pointing out this crucial example.

transact. These are characterised by the price-formation process, the settlement process, and settlement finality.[44] In a textbook market transaction, these three phases takes simultaneously place in the exchange of a good against money. However, as the complexity increases, these three phases become conceptually and practically distinct.

In the crypto world, naked blockchains and layer 1 protocols are settlement technologies, whereby the settlement is probabilistic and regulated by the consensus protocol. Meanwhile, layer 2 and layer 3 protocols aim to upscale this settlement capability, operating as trading venues and facilitating the price-formation process of various crypto-assets which are not native tokens. However, distributed ledgers can technically perform only probabilistic settlements of blockchain transactions. This does not allow for legal finality, nor does it offer the chance to reverse the transaction in all of the instances in which the law deems necessary (for instance, when the transaction is fraudulent or concluded under duress).

As previously discussed, Coasean bargaining requires a clear initial allocation of property rights and negligible transaction costs. Even assuming that blockchain can actually facilitate price formation through crypto markets and provide more efficient settlement capability through DLT consensus protocols, it cannot provide legal finality, which is the key element in ensuring the clear definition of property rights. Consequently, at the very least, the law should provide legal finality to blockchain transactions and this not only means sanctioning the legal validity of such transactions but also includes active interference in the settlement phase where the transaction needs to be reversed according to the law.

Conceptually, this is not significantly different from the role of the law in the off-chain environment. What differs however are the sources of transaction costs and the clarity of allocation of entitlements as well as the tools and techniques that the law must use. This clearly runs counter the ideological imperatives of the initial proponents of blockchain, in the liberal crypto-anarchist and cypherpunk communities as well as in the more recent restatements of these types of approach. However, analysis of the transaction dynamics through a Coasean lens clearly highlights that external interferences are still necessary to make sure that the social costs associated with blockchain are efficiently addressed. Consensus protocols, in and of themselves, are unable to provide an infrastructure that allows transacting parties to internalise externalities privately through decentralised contracting and allocative mechanisms.

We categorise externalities generated by blockchain activities according to the different interactions such activities with third parties. The rationale behind this approach is that different types of interaction lead to inherently different externalities and different failures of a blockchain to internalise such externalities. Consequently, the role of the law to address these externalities also differs, as detailed in Section V.

A way of conceptualising the different externalities created by blockchain is to distinguish them according to the following categories:

a) *Indirect interactions with the blockchain*: Externalities can be generated indirectly by the economic activities carried out in the given blockchain. The simplest example thereof is the environmental externality generated by the mining process, which is necessary to validate transactions.[45] Also of relevance here is the increase in systemic risk generated by the crypto economy and the challenges this brings to

[44] Johannes Rude Jensen and Omri Ross, "Settlement with Distributed Ledger Technology" (Proceedings of the Forty-First International Conference on Information Systems, India, 2020).

[45] See, for instance, Moritz Wendl, My Hanh Doan and Remmer Sassen, "The Environmental Impact of Cryptocurrencies Using Proof of Work and Proof of Stake Consensus Algorithms: A Systematic Review" (2023) 326 Journal of Environmental Management 116530.

monetary policy and financial stability.[46] Finally, into this category also fall all instances of money laundering and terrorism financing courtesy of the anonymity of blockchain.[47]

b) *Direct interactions with the blockchain*: Externalities can be generated by direct interactions between actors carrying out and facilitating crypto activities and blockchain users. These can arise from different types of risk, including operational or legal.

The easiest conceptualisation of this type of externalities is the risk of a bug or a hack, not directly in the naked blockchain but in the layer 2 smart contracts (eg, DAO), or with custodians, crypto exchanges, and so forth.[48] Directly hacking the blockchain is thought to be difficult, but not impossible if malevolent nodes possess enough computational power.[49] Parallel to the externalities generated by operational risk, one may also think of the externalities generated by legal risks related to the key players facilitating the crypto economy. One key example here is the bankruptcy risk of wallets and custodians.[50] Another noteworthy issue is the legal nature of DAOs and the liability status of their members.[51]

c) *Interactions within the blockchain*: Other adverse external effects may be generated by interactions within the blockchain, meaning the mechanisms and the actors designated to set and maintain a functioning protocol. This is traditionally referred to as "blockchain governance" and is – to this day – largely based on informal interactions and decision-making of a small group of people, namely significant miners and core developers. These individuals can impose external effects on all users of the technology via changes in the protocol that are compatible (soft forks) or incompatible (hard forks) with the previous version of the protocol. Hard forks are particularly problematic in terms of property entitlements as they generate two different and incompatible ledgers with unclear effects for end-users.[52]

These three types of interaction of third parties with blockchain and with blockchain participants are very different. However, there is a common thread linking all of them. At least at this stage of technological development, it is not possible algorithmically to determine and regulate all possible courses of action related to any given transaction. In other words, contracts are incomplete.[53]

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[46] See, respectively, Edoardo D Martino, "Monetary Sovereignty in the Digital Era. The Law & Macroeconomics of Digital Private Money" (2024) 52 Computer Law & Security Review 105909; Edoardo D Martino, "Regulating Stablecoins as Private Money between Liquidity and Safety. The Case of the EU Market in Crypto Asset (MiCA) Regulation" (2022) Amsterdam Center for Law & Economics Working Paper 2022-07 available at <https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4203885> accessed 22 March 2024.

[47] Lars Hornuf and Others, "Cybercrime on the Ethereum Blockchain" (2023) CESifo Working Paper No. 10598 avaialble at <https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4538046> accessed 22 March 2024.

[48] For a survey on the matter, see Ben Charoenwong and Mario Bernardi, "Lessons from a Decade of Cryptocurrency Hacks, 2011–2021" in Henrik Cronqvist and Desiree-Jessica Pely (eds), *The Elgar Companion to Decentralized Finance, Digital Assets, and Blockchain Technologies* (Cheltenham, Edward Elgar 2024) 147.

[49] Sarwar Sayeed and Hector Marco-Gisbert, "Assessing Blockchain Consensus and Security Mechanisms against the 51% Attack" (2019) 9 Applied Sciences 1788.

[50] Matthias Haentjens, Tycho De Graaf and Ilya Kokorin, "The Failed Hopes of Disintermediation: Crypto-Custodian Insolvency, Legal Risks and How to Avoid Them" (2020) Singapore Journal of Legal Studies 526.

[51] Borgogno and Martino (n 16) 20.

[52] To the best of our knowledge, this issue has received no attention in the literature. In the legal realm, the issue is scrutinised only for tax purposes. See, for instance, Doris Stacey Gama, "Creating Something out of Nothing: Taxation of Cryptocurrency Hard Forks" (2021) 31 Albany Law Journal of Science and Technology 258.

[53] For a review of the most relevant theoretical contributions in the field, see Jean Tirole, "Incomplete Contracts: Where Do We Stand?" (1999) 67 Econometrica 741.

In these settings, the concept of a contract is not used in its technical legal meaning, but rather for its economic connotations, designating any sort of implicit or explicit agreements on the allocation of assets and entitlements that can be entered into and executed according to different modes. The economic connotations of the concept of a contract are broader than the legal ones, and legal contracts represent only a subset of what can be understood as contracts.[54]

This methodological refinement elucidates the role of the law in supporting efficient blockchain transactions.[55] Agreements on entitlement allocation and their contingencies can be encoded and deployed in blockchain. But their incompleteness invariably requires methods to ex-post complete contracts or, in other words, to allocate residual control rights, at least at the stage of the legal finality of the transaction.[56] Therefore, if blockchain transactions are in some respect incomplete, then the issue is what would it take to complete them algorithmically, if that is possible at all. In other words, one should ascertain whether encoding (almost) complete contracts can be done at transaction costs close to zero.

In contrast, if the completeness of the contract cannot be achieved ex-ante through algorithmic governance, the second problem to address here is who holds the residual control rights according to the technological design of the blockchain and its application. In the Coasean framework used for this analysis, it implies that contract incompleteness and ex-post control allocation prevent clear allocation of property rights.

If code or other features of blockchain technology allow parties to transact at no transaction cost and with clearly allocated property rights, then the law should sanction this and offer enforcement vis-à-vis third parties, ensuring the legal finality of the transaction. However, where this is not possible by means of technology, the law should take care of the allocation of entitlements to approximate efficiency in blockchain.

V. The law as the missing piece

The prevalence of the externalities associated with blockchain, as identified above, underscores the necessity for regulatory intervention. A comprehensive analysis of what the ideal regulatory framework would be to address each individual externality exceeds the scope of this contribution.[57] It is nevertheless essential to recognise that regulatory solutions may vary across jurisdictions, thus precluding a uniform one-size-fits-all approach. We make explicit references to relevant solutions of various jurisdictions whenever necessary.

1. General principles

Rather than prescribing specific regulation, we propose a set of regulatory principles aimed at mitigating the externalities stemming from various blockchain interactions. This highlights the key tools to analyse specific blockchain legislations or design new ones.

It is important here to clarify that our objective is not to establish strict regulation that would curb the use of blockchain technology by avoiding all potential risks; nor do we advocate providing unconditional legal endorsement of blockchain activities. Instead, our

[54] For a more detailed analysis of this distinction, see David Martimort, "Contract Theory" *The New Palgrave Dictionary of Economics* (Palgrave Macmillan UK 2017) available at <https://doi.org/10.1057/978-1-349-95121-5_2542-1> accessed 22 March 2024.

[55] On incomplete contracting and the blockchain, see Vatiero (n 19).

[56] Supra, text to n 43.

[57] In the same vein, also the specific analysis of the various legislative initiatives is also beyond our scope of analysis.

aim is to establish regulatory principles that effectively manage the social costs associated with blockchain. In Coasean terms, this entails leveraging the law's enabling and essential functions to internalise or at least minimise blockchain-generated externalities, thereby enhancing social welfare.

Broadly speaking, there are two main regulatory approaches to consider: leveraging existing legal principles and rules; or drafting specific and new norms tailored to blockchain activities. Both approaches have their advantages and drawbacks. In the current regulatory landscape, the EU approach with its new Markets in Crypto Assets Regulation (MiCAR) can be regarded as a paradigm of the second approach.[58] In contrast, the US approach focusing on the power and competences of existing regulatory agencies can be regarded as a paradigm of the first.[59]

On the first approach, following the seminal work by Merton, it is advisable to map activities performed by new technology (here blockchain/DLT) and then using guiding principles to regulate them that were adopted in the traditional financial market.[60] This approach would guarantee regulatory consistency and further the policy objectives central to current regulatory framework.[61] Moreover, it economises on the political costs of legislating. These costs can be sizeable, especially in some jurisdictions. Moreover, this approach may reduce the risk of regulatory capture by the industry which may attempt to lure lawmakers into inappropriately light regimes.[62]

On the other hand, plainly applying existing legislation to new phenomena implies potentially significant costs, as existing rules, for instance on securities offerings and trading, may not align with the unique characteristics of blockchain issuance and coin transactions. The existing legislation is often thought to fit traditional off-chain applications, and expanding its scope to encompass new technological phenomena may fail to recognise the unique points of the new technology. This means that the existing regulation may be unable to curb blockchain-specific externalities and, conversely, may reduce blockchain-specific efficiency gains, especially in terms of transaction cost reduction. Another challenge with this approach is creating a suitable connection between activities and entities in the crypto space and their traditional finance equivalents, along with the necessary legal foundations. For example, regulators are exploring potential licensing and regulation of stablecoins under categories such as banks, payment systems, or non-bank entities like payment service providers.[63] Enforcement poses another hurdle to address.

For instance, the ongoing debate in the US regarding the classification of cryptocurrencies as securities exemplifies the challenges of applying outdated legislation to blockchain transactions. Since the emergence of the first initial coin offerings (ICOs), scholars, regulators and the industry as a whole have engaged in an intense and still ongoing debate about the doctrinal nature of cryptocurrencies and whether they could be characterised as securities in line with the long-established *Howey* test.[64] This discussion

[58] Regulation (EU) 2023/1114 of the European Parliament and of the Council of 31 May 2023 on Markets in Crypto-Assets (MiCAR) (2023) OJ L150/40.

[59] Edoardo D Martino, "Cryptocurrencies and Stablecoin Regulation: A Framework for a Functional Comparative Analysis" in Edoardo D Martino, Hossein Nabilou and Alessio M Pacces (eds), *Research Handbook in Comparative Financial Regulation* (Edward Elgar Publishing, forthcoming).

[60] Robert C. Merton, "A Functional Perspective of Financial Intermediation" (1995) 24(2) Financial Management 23.

[61] For an application to the field of Decentralised Finance, see Matteo Aquilina, Jon Frost and Andreas Schrimpf, "Decentralized Finance (DeFi): A Functional Approach" (2024) 10 Journal of Financial Regulation 1.

[62] Supra, text to n 15.

[63] In the EU, MiCAR reserves the issuance of eMoney Tokens (eMT) to entities already licensed as credit institutions or eMoney institutions, whereas Asset Referenced Tokens (ART) can be issued by credit institutions and new ART issuers specifically authorised. See, respectively, Arts. 48 and 16(1).

[64] For an early contribution, see Scott D Hughes, "Cryptocurrency Regulations and Enforcement in the US" (2017) 45 Western State Law Review 1.

does not advance our understanding of the specific externalities, efficiency gains, and desirable regulation related to cryptocurrencies though. Rather, it displays an obsession of some legal scholars and practitioners with definitional questions and semantic connotations. There is only one reason why the discussion still (and exceptionally) remains relevant: due to political differences, the U.S. Congress has long struggled to legislate on the matter, and, therefore, a pragmatic extension of established legal principles has been the only viable legal response to date.[65] In fact, labelling cryptocurrencies as securities or commodities under existing laws is crucial to assign regulatory and enforcement powers to different agencies, such as the Securities and Exchange Commission (SEC) and the Commodity Futures Trading Commission (CFTC). In the absence of specific legislation, such designation becomes crucial to ensure that the industry is not left completely unregulated.[66]

For these reasons, simply applying existing laws to blockchain transactions is deemed desirable (ie, a Coasean improvement) *only* if the functionally equivalent off-chain transaction exhibits precisely the same externalities and the same efficiency gains. Nonetheless, sticking with the existing legislation can be considered a third-best solution only; the optimal (first-best) solution entails internalising social costs via bespoke regulation, with the second-best being blockchain-specific law, especially in cases where the political hurdles of enacting new legislation are prohibitively high.

From a Coasean perspective, improving social welfare means that a transaction should be organised on- or off-chain depending on the comparative advantages that such organisational decisions provide at the margin.[67] The direct implication of this proposition is that there should be a level playing field for the on- and off-chain options. Once this has been achieved, then private actors can better determine, through contracts, where the transaction actually takes place. Crucially, if the costs and benefits brought about by on- and off-chain transactions are not identical, the risk is that the playing field remains level on paper only. Instead, what we should aim for is a *de facto* level playing field.

In this regard, the recent EU DLT Pilot Regime represents an interesting approach to experiment with new blockchain applications.[68] In the current phase, where the technology is still developing, a sandbox regime can help balancing the potential trade-offs between innovation and regulatory oversight, allowing for a staged process towards a Coasean optimum.[69]

2. Towards blockchain-specific regulation

When the externalities and the benefits of on- and off-chain transactions are not identical, how can such a de facto level playing field be reached? Based on the previous analysis, blockchain-specific law should complement blockchain transactions by looking at two key dimensions: (1) the type of interactions with third parties who are exposed to the social

[65] In May 2024, the US House of Representatives passed a *Financial Innovation and Technology for the 21st Century Act* (H.R. 4763), which proposes to regulate digital assets in the United States. The Bill passed, however, against the vocal opposition of President Joe Biden and SEC Chair Gary Gensler. The outcome of the project in the Senate is still very uncertain.

[66] Chris Brummer, Yesha Yadav and David T Zaring, "Regulation by Enforcement" (2023) 96 Southern California Law Review 1297.

[67] Ronald H Coase, "The Nature of the Firm" (1937) 4 Economica 386, 396.

[68] Regulation (EU) 2022/858 of the European Parliament and of the Council of 30 May 2022 on a pilot regime for market infrastructures based on distributed ledger technology (2022) OJ L151/1.

[69] For an analysis of the virtues and potential of regulatory sandboxes, see Wolf-Georg Ringe and Christopher Rouf, "Regulating Fintech in the EU: The Case for a Guided Sandbox" (2020) 11 European Journal of Risk Regulation 604. For a more specific introduction of the EU DLT Pilot regime, see Dirk A Zetzsche and Jannik Woxholth, "The DLT Sandbox under the Pilot-Regulation" (2022) 17 Capital Markets Law Journal 212.

costs of blockchain, whether those be indirect, direct, or within the blockchain; and (2) the level of technological solution necessary to handle contract incompleteness in terms of transaction cost reduction and the efficient allocation of property rights.

a) Indirect interactions

In the case of indirect interactions with blockchain, when third parties cannot or do not want to be part of crypto transactions, the law plays an essential role as third-party effects are non-contractible, especially in all cases in which these effects are systemic (such as environmental externalities and financial stability). Having an *essential* role here means that the applicable law should mimic the efficient allocation of entitlements should a market have existed. To do so, the legislature has the typical Pigouvian measures at its disposal. Specifically, the law can affect blockchain activity by impacting on prices (through taxes) or quantity (through substantive requirements). From a regulatory perspective, this implies the need to be able to identify those who are subject to such measures. Typically, this is done through an authorisation regime.[70] Clearly, authorisation regimes increase transaction costs and have potentially anticompetitive effects as they can be understood as barriers to entry.[71] On the other hand, such regimes are widely considered a cost-effective way of handling this type of externalities and represent a regulatory strategy widely employed in off-chain transactions. This approach is in line with considering blockchain-specific regulation a second-best solution.

Interestingly, to achieve this second-best solution and unleash the real potential of blockchain application, in the presence of externalities caused by indirect interaction with blockchain, it is necessary to identify blockchain users clearly, which goes against the original promise, of anonymity for parties transacting in a blockchain. In the same vein, some level of centralisation remains necessary and unavoidable.

The key challenge for this type of *essential* regulation is that the regulator may lack the relevant information to set the price and quantity efficiently. Indeed, in the absence of externalities, the market could better elicit individuals' preferences and reach efficient equilibria. However, this problem is not specific to blockchain, and is common to all highly regulated industries. From a technological perspective, this represents a residual category. As technology evolves and blockchain adoption increases, externalities caused by indirect interactions are likely to decrease as more parties will take part in blockchain transactions. To the limit, this category should address only systemic externalities as individual parties are structurally unable to account for those.[72]

b) Direct interactions

The second category of blockchain externalities relates to the direct interactions among parties acting in the blockchain economy, where the parties could encode their relationships between themselves. However, contractually encoding such relationships is not always possible or cost-effective. In this case, the law shall have an *enabling* role.

[70] This approach is by and large adopted by MiCAR. For an introduction to the European regime, see Filippo Annunziata, "An Overview of the Markets in Crypto-Assets Regulation (MiCAR)" European Banking Institute Working Paper Series n 158/2023 available at <https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4660379> accessed 22 March 2024.

[71] Mukesh Eswaran, "Licensees as Entry Barriers" (1994) Canadian Journal of Economics 673.

[72] In this respect, the EU made a peculiar choice when it comes to the environmental related externalities caused by consensus mechanisms, in contrast with our analysis. To incentivise more "environmentally friendly" solutions, the regulation requires issues of crypto assets to include "information on the principal adverse impacts on the climate and other environment-related adverse impacts of the consensus mechanism used to issue the crypto-asset" in their whitepaper. See Art 6(1)(j) MiCAR.

Clearly encoding entitlements and efficiently transacting around them is theoretically possible and the law should make it practically feasible.

To achieve this goal, the law should clearly define the entitlements, including the responsibilities, of new blockchain intermediaries.[73] These should be subject to transparency and disclosure requirements, and to further substantive requirements aimed at protecting weak parties. This approach is functionally similar to existing securities regulation but, crucially, the specific requirements do not need to be the same. On the contrary, these should be adjusted to the specificities of blockchain transactions.[74]

In this case, the key challenge in designing such regulatory requirements is in balancing the risk of curbing innovation and excessively increasing transaction costs via compliance requirements.

From a technological perspective, this category could become more and more important as the technology and blockchain adoption evolve. One specific aspect of this evolution worth mentioning here is asset tokenisation.[75] Moreover, if more asset classes can be transacted over blockchain, the realm of direct interactions also increases.

c) Blockchain governance

Finally, the last category of externalities to discuss are those generated by interaction within the blockchain (aka blockchain governance). In this realm, one can imagine many heterogeneous phenomena, ranging from informal and off-chain governance up to fully on-chain and algorithmic governance. While the former exists and is the main form of blockchain governance, for instance in the Bitcoin blockchain, the latter represents the holy grail for blockchain proponents.[76]

Notwithstanding different technological specifications of blockchain governance, the role of the law does not change. Blockchain governance sets the rules of the game for all parties who want to transact over that particular blockchain, including the consensus protocol and validation mechanism. This set of rules constitutes the key market infrastructure, allowing parties to transact around their entitlements.[77] Consequently, those who have the ability to set and update such infrastructure should be considered gatekeepers. Accordingly, the law should clearly define the entitlements of such gatekeepers, in terms of rights and responsibilities.[78] The legal tools to do so would however differ. In the case of informal and off-chain governance, ex-post strategies can be effective and set the appropriate incentives. In the case of on-chain algorithmic governance, ex-ante strategies, including authorisation, are preferable.

Here, the role of the law is similar to that of corporate and organisational law. However, private enforcement through litigation should be complemented by a strong

[73] See, for example, Art 59 ff MiCAR.

[74] The EU legislature approached these matters by designing a new regulatory regime and procedure that closely mirrors those existing for traditional securities. In this respect, Annunziata talks of “mifidisation of MiCAR.” See Annunziata (n 70) 56.

[75] For an introduction to the topic and its legal implications, see Rosa M Garcia-Teruel and Héctor Simón-Moreno, “The Digital Tokenization of Property Rights. A Comparative Perspective” (2021) 41 Computer Law & Security Review 105543.

[76] See, for instance, Wessel Reijers and Others, “Now the Code Runs Itself: On-Chain and off-Chain Governance of Blockchain Technologies” (2021) 40 Topoi 821.

[77] Angela Walch, “The Bitcoin Blockchain as Financial Market Infrastructure: A Consideration of Operational Risk” (2015) 18 New York University Journal of Legislation & Public Policy 837.

[78] Along this line of thought, some authors proposed to impose fiduciary duties on software developers, see Angela Walch, “In Code(rs) We Trust: Software Developers as Fiduciaries in Public Blockchains” in Philipp Hacker and Others (Eds), *Regulating Blockchain. Techno-Social and Legal Challenges* (Oxford, Oxford University Press 2019).

system of public enforcement to avoid rational apathy among blockchain users, especially in cases where judicial remedies may be practically unavailable given the tamper-resistant nature of blockchain. Relatedly, blockchain protocols should always encode a backdoor provision allowing tampering with the blockchain in strict and typical cases provided by the law, mimicking cases in which the law can declare a contract null and void because, for instance, it was concluded under duress or violated mandatory legal norms.

In summary, this section has proposed several regulatory principles to handle the social costs of blockchain. By and large, these principles are not jurisdiction-specific. However, the implementation of these principles may involve a number of trade-offs, for instance in terms of authorisation requirements or supervisory oversight. How to settle these trade-offs is not self-evident and largely depends on the policy choices of individual legislators.[79]

VI. Conclusion

In conclusion, this article has delved into the intricate relationship between blockchain technology and the social cost it generates, offering insights into the regulatory challenges and potential solutions thereto. Through the lens of Coase's seminal framework, it has become evident that while blockchain promises to transform economic activities and greatly lower their transaction costs, it also presents inherent limitations and externalities that may necessitate regulatory intervention.

Our analysis has revealed that blockchain technology, despite its decentralisation and efficiency aims, does not inherently eliminate externalities but rather redistributes them in novel ways. From environmental impacts to operational risks and governance challenges, the social cost of blockchain transactions is varied and complex. Moreover, the incomplete nature of blockchain contracts underscores the indispensable role of the law in facilitating efficient transactions and addressing externalities.

Moving forward, regulatory interventions must strike a delicate balance between fostering innovation and safeguarding against adverse effects. The proposed regulatory principles in this article provide a roadmap for policymakers to navigate this complicated landscape, emphasising the importance of tailored approaches that consider the unique characteristics of blockchain interactions.

Our framework and findings represent a solid starting point for further research investigating specific externalities brought about by specific applications of the blockchain, such as real-world asset tokenisation, non-fungible tokens and so forth.

Furthermore, the article has underlined the need for ongoing dialogue and collaboration among stakeholders to ensure that regulatory frameworks keep up with technological advancements. As blockchain continues to permeate various sectors of the economy, it is imperative that regulatory efforts remain adaptive and responsive to emerging challenges and opportunities.

In essence, the law serves as the missing piece in unlocking the full potential of blockchain technology while mitigating its social costs. By embracing a pragmatic and nuanced approach to regulation, policymakers can foster an environment conducive to innovation, efficiency, and social welfare in the blockchain ecosystem.

[79] For a framework to approach the comparative aspect of blockchain regulation, see Martino (n 59).

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