Decentralization, Blockchain, Artificial Intelligence (AI): Challenges and Opportunities

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Abstract

This paper evaluates the conflict between the emerging forces of decentralization and artificial intelligence. In general, the forces that lead towards decentralization are often grounded in idealism rather than economics. As a result, new technologies, such as artificial intelligence, are unlikely to easily coexist with decentralized technologies and platforms. This has implications for innovation management.

Contents

1 Introductions

This paper argues that history predicts that decentralized technologies face powerful headwinds. It then uses the economic forces underlying these headwinds to evaluate the future trajectory of blockchain and AI.

1.1 What is decentralization?

Decentralization is ultimately about making deliberate choices about the distribution of power in a product or service ecosystem (Catalini and Michelman, 2017; Tucker and Catalini, 2018; Cheng et al., 2019). Typically, managers have been encouraged to think about embracing centralized power in the hands of a single firm and taught to think of it as a strategic imperative. However, decentralization ultimately hopes to use new technologies to allow interactions between users to happen seamlessly without the intervention of the management of a single focal firm.

One of the movements that underpins recent movements towards decentralization is 'Web 3.0'.[1] This is a movement towards the next generation of the internet built on blockchain and smart contracts. In "Web 1.0", users are consumers of the internet, as they are only allowed to read content from the internet. In "Web 2.0", users are also the suppliers of the internet, creating original content such as blog postings and social media. The idea of "Web 3.0" is to have the users interact using decentralization technology like the blockchain, instead of interacting through centralized platforms. Essentially, Web 3.0 is a movement towards the decentralization of the internet, trying to democratize and decentralize interactions on the internet.

[1] For example, https://www.economist.com/business/2022/01/29/will-web3-reinvent-the-internet-business, and https://www.forbes.com/sites/forbestechcouncil/2023/08/09/20-tech-experts-on-what-businesses-should-do-now-to-prep-for-web3/?sh=2bbec8a9d6d0. [Accessed 9/22/2023]

1.2 What is not decentralization?

The ideas of Web 3.0 and decentralization have also often been conflated with a variety of applications of blockchain technology, such as bitcoin and digital currency. Although digital currency is a useful first use case and test of the ideas that a product, such as currency, can be decentralized and thrive without the sponsorship, steering, and control of a central bank, it is merely an application of decentralization, not its essence. In addition, bitcoin itself often displays a lack of decentralization due to scale economies in mining (Malik et al., 2022).

The ideas of Web 3.0 and decentralization have also often been conflated with concepts such as the "metaverse," which describes a single, universal, and immersive virtual world.[2] However, the metaverse is not a reorganization of how firms and products are managed. Instead, it is an attempt to move the physical to the virtual using several technologies such as virtual reality and augmented reality. In addition, it is a somewhat confusing example, in that several high-profile examples of the metaverse, such as the efforts of the firm previously known as Facebook, now known as Meta, to try and control its development, seem to suggest sponsorship by a single firm. Such efforts are not manifestations of decentralization.

2 Why Decentralization?

2.1 The product tools underpinning the current move to decentralization: Blockchain and Smart Contracts

Decentralization is about making deliberate choices about the distribution of ownership, functions, and decision-making power from a central authority to the hands of participants. A large literature in economics demonstrates that the distribution of power matters because it shapes the incentive structure and, ultimately, the market outcomes, in an ecosystem (Bresnahan (1989)). The power distribu-

[2] Source: `https://about.meta.com/metaverse/` [Accessed: 10/5/2023]

tion determines the incentive structure of agents in an ecosystem, which, in turn, shapes their behavior. One key risk of concentrated economic power is that some firms could engage in anticompetitive behavior that ultimately hurts consumers (Lerner, 1995; Zeuthen, 2018). A literature in political economy has shown that decentralization of power changes political institutions, which may then lead to higher economic growth due to the change in trust and incentive structure (Treisman, 1999; Manor, 1999; Cai and Treisman, 2006; Enikolopov and Zhuravskaya, 2007). As such, decentralization is a means to an end.

At the highest level, blockchain is a technology explicitly built to allow decentralization. This is because it is built explicitly to allow transparency, security, and immutability at scale. Blockchain is a distributed ledger technology. This means that blockchain is essentially a record-keeping tool, and the process of creating new records and the storage of old records is done across many participants in the network. Blockchain combines cryptography and economic incentives in a smart way (Halaburda, 2018). The incentive structure motivates blockchain participants to collectively and honestly validate transactions in the system in equilibrium. The use of cryptography allows data records to be verifiable and transparent to the public and ensures that the entire data history is immutable (Altmann et al., 2019).

Blockchain was initially designed for cryptocurrency and, more specifically, to serve as the basic infrastructure for bitcoin. Over time, people realized that the technology could be adopted more widely (Catalini, 2017); that data records can be computer codes, rather than data in its narrowest definition. Blockchain has the potential to decentralize digital interactions, from financial transactions (Csóka and Jean-Jacques Herings, 2018) to supply chain management (Chod et al., 2020), from removing certain intermediaries to decentralizing the entire internet. As a result, the notion of "smart contracts" emerged. Smart contracts are collections of IF–THEN statements on the blockchain. Therefore, one can think of the codes of smart contracts as contract terms. When a pre-specified IF condition is met, actions specified in the THEN statement will be executed. The contracts are considered 'smart' because the computer programs continuously check for the fulfillment of the IF conditions and will automatically execute the THEN statements when the IF conditions are met. Given that contracts are used extensively in society, the adoption of smart contracts may significantly increase efficiency and innovation. In fact, there are already numerous innovations based on smart contracts, including decentralized finance (DeFi), decentralized autonomous organizations (DAOs), and non-fungible tokens (NFTs).

2.2 The advantages of decentralization

This section describes the key benefits of having decentralized systems, which are, increased fairness in the system, security in terms of decreased risk of single point of failure, and promoting transparency and trust in the system.

2.2.1 Fairness and Asset Ownership

By design, decentralized systems can be a very inclusive form of innovation because without a central firm acting as the gatekeeper, in theory, anyone can participate and contribute. For many users, this perception of fairness, more evenly distributed power, is the key motivator for opting for decentralization.

Decentralized systems also promote a clear delimitation of who owns digital assets. Without accurate and inexpensive bookkeeping, it is difficult to ensure that everyone is fairly compensated for their contribution to an ecosystem. These two challenges are amplified for digital products, as they can be easily replicated and shared at no cost. The use of blockchain technology could directly address this friction by tokenizing the intellectual property (IP) on the blockchain, clearly defining ownership of an IP, tracing how the IP has been used, and automatically compensating inventors and creators when their IP has been used.

In terms of setting up proper incentive structures in blockchain systems, users are rewarded by tokens on the blockchain for solving specific problems. The tokens are valuable because users can either exchange them in the financial market, or can use them for voting in the system in the future. If users' solutions are broadly applicable to other cases, they can file an Intellectual Property of the solution using the blockchain, and can license it for future use. Because of the transparency of the reward structure and clear definition of IP, trust could be higher in open-source AI systems, which in turn could motivate more developers to contribute to the development of AI (Lerner and Tirole, 2002). These features prompt inventors and creators to fully disclose their information on the blockchain increasing access (Catalini and Gans, 2020; Cai et al., 2023).

Moreover, tokenization on blockchain not only creates incentive for secure book-keeping, but can also serve as a commitment device that stops the decentralized platform from exploiting network participants, and improve coordination among them (Bakos and Halaburda, 2022a). This commitment to decentralization increases user participation in the system (Sockin and Xiong, 2023).

Blockchain has the potential to provide disadvantaged groups with better access to services and information. A prominent use case of blockchain is to provide access to financial services in regions with poor banking systems. For example, in the recent war between Ukraine and Russia, blockchain has helped Ukraine by collecting donations from all over the world and sending them to the Ukrainian government in a faster and cheaper way, compared to traditional remittances[3] Another example is better access to information in regimes that have severe government censorship. The startup, Infnote, provides a decentralized application (Dapp) that offers this service, allowing users in countries with censorship to share government-censored information, including news articles and political commentarird (Zhang et al., 2020).

Another example has been recent inventions of blockchain-based weather insurance products that are offered to farmers in underserved regions.[4] Historically,

[3]Source: https://www.wired.com/story/ukraine-crypto-refugee-aid/ [Accessed on 9/25/2023]

[4]Source: https://arbolmarket.medium.com/how-blockchain-technology-will-transform-the-weather-insurance-industry-24a0690d47b8 [Accessed on 9/25/2023]

validating claims in underserved regions can be challenging due to large overhead costs associated with verifying the processing of claims in these regions. With blockchain, weather sensors are installed in these regions, and once they detect weather events such as heavy rainfall, smart contracts will automatically send payments to farmers. The use of blockchain improves the accuracy and transparency of claim processing, as well as reducing transaction costs associated with validating claims. The technology therefore extends insurance services to disadvantaged farmers in regions where traditional insurance firms are unwilling to serve. Furthermore, blockchain can improve the inclusivity of financial services in online peer-to-peer lending markets (Chung et al., 2023).

Lastly, thanks to the decentralized nature of blockchain, it can create an inclusive environment for users of diverse backgrounds to collaborate Lumineau et al. (2021). This leads to moreinnovation (Feldman and Audretsch, 1999; Østergaard et al., 2011).

However, we recognize that there are still barriers to the kind of universal adoption that might guarantee access because the underlying technology is complex and hard to explain to people due to the use of cryptography. Moreover, the blockchain space is filled with jargons, like “private keys and public keys”, “hashing” and “consensus”, and these can be intimidating to users who try to adopt the new technology. The lack of user adoption is problematic because a truly decentralized system depends on having a wide user base, instead of only having specific types of user.

2.2.2 Robustness to Single Point of Failure

These technologies have been developed so that decentralization is robust and is not vulnerable to a single point of failure by design. This gives it resilience.

Decentralized systems reduce vulnerability to a single point of failure relative to centralized systems. This risk is inherent to the systems’ centralized architecture, namely having centralized components like servers and databases. A single point of failure in these centralized infrastructures can be costly to society. For example, the Amazon Web Services Outage in 2020 lasted for several hours, disrupting normal operations of many firms, including trading operations on Coinbase.[5] Centralized systems are also the target of malicious activities. For example, hackers exploited a vulnerability in Target's payment system in 2013, which exposed the payment information of 40 million consumers to the public (SCIENCE and TRANSPORTATION, 2014).

Decentralized systems directly address the inherent vulnerability of systems to a single point of failure (Böhme et al., 2015; Bodkhe et al., 2020). By design, the distributed nature of these systems allows multiple operators to perform the same task and retain the data. As a result, the system can continue to operate if one or a few operators fail, improving the resilience of the system to adverse shocks. Furthermore, having no single target reduces the incentives for hacking behavior because hackers now need to be able to attack a broader swathe of operators.

Like all peer-to-peer technologies, blockchain's distributed nature prevents the potential single point of failure problem with centralization. Beyond what typical peer-to-peer technologies can achieve, the introduction of economic incentives in blockchain, through system tokens like Bitcoins or Ether, makes secure bookkeeping an equilibrium outcome. Without going into too much technical details, the base-layer consensus mechanism makes dishonest behavior easily detectable and unprofitable as long as more than 50% of the computational power (or decision-making power more generally) belongs to network participants who are honest.

However, although decentralized systems are robust to a single point of failure, we caution that there could be cases where central systems can be more secure. A big reason is the clarification of accountability and responsibility in a centralized system. Centralized systems often have the ability to hire professional security

[5] Source: `https://www.theverge.com/2020/11/25/21719396/amazon-web-services-aws-outage-down-internet`[Accessed 9/25/2023]

experts and respond quickly when hacking activity occurred. Therefore, for applications such as national defense and military, having a centralized system may be preferable.

Furthermore, although blockchain technology is decentralized and the information stored on the blockchain is distributed across multiple computers, there are different aspects of decentralization (Zhang et al., 2022), in addition to decentralization at the consensus level. In particular, problems may arise if some use cases of blockchain involve external data sources. For example, some of the if conditions in smart contracts involve checking exchange rates and weather conditions. The potential flaw is the lack of true independence of data sources. Data service providers may obtain duplicate data from an overlapping pool of data resources, such as centralized exchanges. Therefore, the network may not be as decentralized because the data is controlled by centralized servers. This may potentially lead to a higher risk of having single points of failure and re-concentration of power, defeating the ideological aim of blockchain. [6]

2.2.3 Transparency and Trust

Another attraction of decentralization as a movement is that a suite of technologies and tools, such as blockchain, have been developed that explicitly permit decentralization by design. They are explicitly designed to promote trust without a centralized operator or platform offering a guarantee or an active arbitrator of interactions between consumers and sellers or different groups of users.

Transparency is better in decentralized systems by design. In particular, many decentralized systems are open-source, which means that the code that governs key procedures and processes in the system is open to the public for review and discussion. This is in comparison to opacity in centralized systems, as central authorities often have incentives to obfuscate information (Ellison and Wolitzky, 2012; Petrikaitė, 2018), or strategically communicate information in a way that

[6] Source: `https://ethereum.org/en/developers/docs/oracles` [Accessed 9/23/2023]

may mislead consumers (Kartik, 2009).

From a market perspective, improved transparency of production and transaction processes enabled by blockchain technology could mitigate information asymmetry(Iyengar et al., 2021; Wang and Xu, 2022). As a result of a higher level of market transparency, adverse selection and moral hazard are reduced, leading to greater trust and welfare among users in the system (Hui et al., 2016; Klein et al., 2016; Hui et al., 2018). The more trust comes from the fact that, instead of putting trust on a few authorities, users are now putting trust in a network of community members and the system protocol. Increased user trust, in turn, should increase their transactions and economic activities in the ecosystem, making it more prosperous. Recent empirical evidence corroborates this theoretical insight: Jiang et al. (2023) shows that the deployment of blockchain in the supply chain of grocery products increases market transparency, causing more consumer purchases, especially in categories with less trust.

Having a high level of transparency also reduces the incentives of malicious actors. In centralized systems, sometimes malicious behaviors are neglected. In comparison, the transparency of decentralized systems makes malicious activities more easily detectable by collective effort from the entire community. Once spotted, the community can then suggest solutions for potential fixes. This enhanced monitoring capability and collaboration increases the cost of hacking and decreases its benefit simultaneously.

Transparency and trust can also reduce transaction costs. Transaction costs are any costs that are associated with making a transaction. They include the cost of searching for information and performing due diligence, the cost of negotiating the price and other terms of the contract, and the cost of enforcing contracts. Certain types of transaction costs are higher in centralized systems. In particular, the transaction costs associated with dealing with the central intermediary can be high (Cheung, 1969; Leffler and Rucker, 1991). For example, if a firm wants to enforce a contract through the court, then it needs to incur various transaction costs related to interacting with it, including the costs of hiring lawyers, paying court fees, and complying with a complex set of laws and regulations. The process can be financially costly and time-consuming. Working with decentralized systems, on the other hand, saves the transaction costs associated with interacting with intermediaries, because of its decentralized nature.

The invention of smart contracts is important because it allows for the creation of scalable trust without relying on a central authority (Gans, 2019; Baird et al., 2019). Blockchain is more efficient compared to previous generations of peer-to-peer technology because of the clearly-defined rules in the base-layer consensus mechanism, and the economic incentives it introduces (Cong et al., 2023a).. In comparison, last-generation peer-to-peer technologies like torrents do not have any consensus mechanisms to validate the authenticity of the files and do not create incentives for peers to share authentic files.

As discussed, because smart contracts are essentially computer programs, they are constantly running and do not make mistakes like humans do, and they enforce contracts in the matter of seconds when pre-specified conditions are met. This reduces transaction costs compared to centralized systems with gatekeepers. For example, in real estate transactions, buyers need to work with various intermediaries, such as the title companies. Buyers need to pay title companies to investigate title history, and they need to buy title insurance to ensure the accuracy of the title research. In a world with blockchain, however, the technology holds the promise of tracking all past transactions of the house, and therefore little investigation cost and insurance would be needed in this case. With these benefits in mind, we caution that technology itself does not change the incomplete nature of most contracts (Hart and Moore, 1999), and therefore we should think about smart contracts as being able to enhance existing contract-enforcement mechanisms to extend the contract space, instead of completely replacing them (Halaburda et al., 2019). The growing empirical evidence suggests that blockchain can mitigate market inefficiencies from contractual incompleteness (Chen et al., 2023).

3 Headwinds to the forces of decentralization

This section describes that there are natural economic forces that work against decentralization. An obvious one is that essentially the new innovation works against economic forces such as economies of scale and scope because decentralization naturally has diseconomies of scale (Bakos et al., 2021). There may also be coordination costs that are inherent in maintaining centralization. A large literature in economics has demonstrated that centralized systems where a few firms operate can be more efficient than decentralized systems for several reasons: economics of scale and scope (e.g., Stigler, 1958; Panzar and Willig, 1981) , lower transaction costs (e.g., Coase, 1960; Williamson, 1989; Baker and Hubbard, 2001), and lower coordination costs (e.g., Becker and Murphy, 1992; Clemons and Row, 1992). Furthermore, there are the twin challenges of introducing the complexity of having to govern a decentralized system, combined with a lack of accountability if things go wrong.

3.1 Economics of Scale and Scope

Centralized systems increase the efficiency by pooling resources, increasing scale economics (Baumol and Willig, 1981; Stiglitz et al., 1987; Bresnahan and Reiss, 1994). In telecommunications, having a single entity pay the sunk cost of setting up the communication infrastructure is more efficient than having multiple firms pay the cost multiple times.

Scalability means that the technology must find a way to meet expanding network demand at a reasonable cost. Decentralized systems cannot cost much more than the centralized counterpart, either financially or in terms of time, for users to practically adopt the technology. In e-commerce logistics, it is cost efficient for Amazon to invest and establish a logistic system and use it for its large amount of orders. Furthermore, due to economics of scope, centralized systems are typically incentivized to innovate in complementary services as well (Bond and Samuelson, 1987; Chen and Schwartz, 2013; Holmes et al., 2012). For example, Amazon has a highly centralized and streamlined dispute resolution system. The resulting fast logistics and high-quality customer service ultimately reduce the cost of online shopping and increase customer satisfaction.

In comparison, decentralized systems may encounter diseconomies of scale (Sundararajan, 2014). These systems often require duplicated resources in the initial setup and operation stages. For example, decentralized systems need to hire people as operators and each would need to incur some sunk cost, such as the cost of purchasing computers and other equipment, before they can contribute to the systems. Such costs would be lower under centralization due to economies of scale. Adding to the waste of resources, the lack of standardization in decentralized systems can be a problem. For example, decentralized operators may end up using software or protocols that are incompatible with each other, which not only makes the communication between operators costly, but may also decrease consumer experience. For example, as we discussed in the case of peer-to-peer technology, the cost of searching and finding content can be high because of the lack of indexing protocols.

Early examples of blockchain have indicated how economies of scale and scope can haunt attempts at decentralization. Essentially, a system that is costly to use will have less entry by service providers (or users), which increases market concentration. For example, Cong et al. (2023b) show that mining income and Ether owners are concentrated in crypto exchanges and a few network participants. Similar patterns of concentration have been shown in the context of decentralized autonomous organizations (DAOs) (Bakos and Halaburda, 2022b). Realizing potential problems from diseconomies of scale, firms have been actively exploring and innovating "layer-2" technologies for scaling, which are promising steps to push the technological constraint. Cong et al. (2023a) show that a layer-2 technology reduces market concentration among service providers in the system, which, in turn, increases data integrity.[7]

[7] John et al. (2020) argue that the effect of scalability on data integrity, or blockchain security in general, depends on the consensus mechanism. Li (2023) and Mamageishvili and Felten (2023)

3.2 Coordination costs

Coordination costs are the costs associated with coordinating different parties to achieve a common goal. One major benefit of centralization is reduced coordination costs, as the chain of command is clear: parties in a centralized system simply follow the decision made by the central authority. Coordination cost in terms of collectively deciding on actions are therefore minimal. This feature in centralized systems allows the system to make decisions quickly and in flexible ways.

However, the efficiency of this top-down decision-making approach can come at the cost of certain groups of users. For example, once eBay has decided that a consumer could return a product for a refund, that decision is final and the seller of the product typically has no choice but to comply with this decision, even in scenarios where the seller is not at fault such as late delivery due to unexpected adverse weather conditions. In this example, fast dispute resolution experience may not always be fair to sellers.

In decentralized systems, coordination costs are typically higher by their very nature(Krishnan et al., 2003; Spulber, 2019). Each operator in the system is self-governed and no one has absolute controls over information sharing and decision making. This means that the two processes could take a long time and that decentralized information sharing and decision-making could lead to inconsistent results. Besides the content, potential inconsistencies in the format of information sharing could also cause problems, as different operators may follow different protocols. In general, the lack of interoperability among operators is problematic, leading to isolated systems, reducing the number of use cases, and creating inconvenience for users. In terms of decision making, the governance of decentralized operators poses another significant source of coordination costs. Because there is no single authority, decisions about the system are based on reaching consensus among the operators. Therefore, reaching a decision may sometimes reach an

show that there needs to be at least one honest participant in the system (e.g., a layer-2 application) to ensure security.

impasse.

In terms of the coordination of power, the design of the consensus mechanism for validation of transactions is important, as the rule directly relates to the distribution of power. Currently, the most popular consensus mechanisms are either proof-of-work (PoW), which is used by the Bitcoin blockchain, or proof-of-stake (PoS), which is used by the Ethereum blockchain (see a detailed summary in Halaburda et al. (2022)). Both mechanisms can achieve efficient equilibriums under certain conditions (Budish, 2018; Gans and Gandal, 2019; Saleh, 2021). However, while aiming to achieve decentralized governance, both PoW and PoS mechanisms have potential issues in terms of allowing unequal distribution of resources to network participants.

In a PoW network, consensus is determined based on "miners" solving computationally costly problems. The ability to solve these problems depends on the amount of computational power a miner has, relative to other miners in the system, which then determines who gets to validate transactions. In a PoS system, consensus is determined based on how much "validators" stake as collateral, which will be refunded to them only if the transaction is authentic. As a result, validators with more financial resources are more likely to be chosen to validate the transactions.

In both cases, owners of vast computational power and financial resources will have greater influence on the network, meaning that they could propose changes to the network, and their vote will carry more weights in the decentralized governance process. This may lead to re-concentration of power (Makarov and Schoar, 2021; Capponi et al., 2023). Various design choices have been proposed to mitigate the potential problem of re-concentration of power. For example, some PoW systems have been designed to be resistant to specialized computational hardware, such as Application-Specific Integrated Circuits. This restriction increases the participation of users with regular computing devices.[8] On some blockchains,

[8] while discounting the use of specialized computational hardware in a blockchain may increase

the algorithms apply exponential discounting to computing power to limit the effectiveness of large computational power. In addition to the design of the protocol itself, individual users have formed mining pools, which pool their computational power to solve the math problem and share rewards afterwards.[9]

In PoS systems, various delegation mechanisms have been proposed, where users with fewer financial resources can use their tokens to vote for a small number of representatives who will act on their behalf. This creates a more democratic structure, similar to delegation in politics. For example, Benhaim et al. (2021) show that consensus based on a committee (elected by uses in the system with approval voting) generally reaches efficient voting outcomes, but is more scalable than the typical PoS consensus. Similar to the discounting mechanism in PoW systems, some blockchains use algorithms that discount large financial resources in PoS systems, or equivalently propose progressive tax schemes to increase the cost of staking a large amount.

3.3 Dynamic Adaptability

In many countries like the US, regulation of blockchain is still being shaped. This creates large uncertainty for potential users and investors. There are a few major policy debates. The first one is about token classification, concerning whether blockchain tokens should be regulated as securities, currencies, or utility tokens. Unsurprisingly, the SEC argues that tokens are essentially securities[10] and the majority of blockchain companies argue otherwise. The classification of tokens could have great implications for how crypto transactions should be taxed and regulated. Another major policy discussion includes topics on protecting consumers from blockchain frauds. The key here is to balance consumer protection and not

entry for miners, it can also introduce potential security risks and greater sensitivity to market fluctuations (Garratt and van Oordt, 2023).

[9] Mining pools have their own problems. For example, Cong et al. (2021) show that mining pools significantly increase energy consumption in PoW blockchains.

[10] Source: `https://cointelegraph.com/news/sec-labels-61-cryptocurrencies-securities-after-binance-suit` [Accessed 09/23/2023]

stifle innovation. Last but not least, there have been more policy discussions on the implication of using blockchains on privacy, which is the price that users pay for blockchain's transparency. How to get the new technology to comply with privacy policies like the General Data Protection Regulation (GDPR) is not entirely obvious at this stage.

Even in cases with little policy debate, the legal recognition of this new technology has been moving slowly. In particular, most countries do not qualify smart contracts on a legal basis, with Italy being the exception.[11]. Additionally, whether blockchain can be used as evidence in a court also varies by jurisdictions.[12]

Since regulatory uncertainty could prohibit both innovation and user adoption of blockchain (Marcus, 1981; Stern, 2017), blockchain startups have been increasingly talking and collaborating with regulators to shape regulatory landscape together. Meanwhile, many start-ups have chosen to self-regulate and actively comply with existing regulations. In terms of token classification, many blockchain startups have already chosen to comply with securities laws during their initial coin offerings.[13] Next, in terms of customer protection, as of 8/15/2023, most crypto exchanges have implemented Know Your Customer (KYC) and Anti-Money Laundering (AML) procedures, verifying user information such as social security numbers before users could trade cryptocurrencies. Lastly, in terms of data regulations, blockchain companies have increasingly chosen to comply with these regulations, by using data encryption and anonymization. Some companies also systematically self-audit their data practices using Privacy Impact Assessments (PIAs).

[11] Source: https://www.linklaters.com/en-us/insights/blogs/fintechlinks/2019/fintech-italy-affirms-legal-effectiveness-of-distributed-ledger [Accessed 9/27/2023]

[12] Source: https://www.lexology.com/library/detail.aspx?g=b7952a8d-578e-4def-ae67-acf686af48e7[Accessed 9/27/2023]

[13] SEC's guidelines about ICOs: https://www.sec.gov/securities-topics/ICO. [Accessed: 9/25/2023]

3.4 A Historical Analysis of these headwinds through history

The history of economics underlying the diffusion of innovation illustrates the interaction between economics and regulation and the forces against decentralization in innovation. A recurring theme is that:

1. An existing industry has scale economies that lead it to be centralized in the hands of the few
2. A new technology promises a dismantling of these scale economies by reducing the need for a physical manifestation of that product. This technology initially appears to promise the possibility of decentralization, and indeed that is part of its early appeal.
3. Eventually, new scale economies or regulatory challenges emerge for the new technology which again leads to centralization

Such concentration naturally leads to concerns and instances where firms execute their market power not to benefit consumers, but instead simply increase their profitability and effectively reduce competition, and in the longer term, innovation, and ultimately consumer welfare. We use these examples to highlight that the pattern we observe for blockchain technologies of a movement towards decentralization and the headwinds to decentralization is not unique to blockchain.

3.4.1 Telecommunications

Step 1 The postal service has natural scale economies. Each letter carrier becomes more efficient the more dense the delivery network they cover. As a result, many governments have essentially recognized that postal service should be nationalized, as the natural force of economies of scale means that otherwise they have the characteristics of a natural monopoly.

Step 2 The advent of telecommunications technology in the 19th century reduced the postal delivery time of messages from days or weeks to seconds. As such, this technology promised a democratization of access to communication and a reduction of reliance on centralized forms of information dissemination which could be controlled by a few gatekeepers such as the postal service.

Step 3 However, telecommunications eventually also began to exhibit scale economies. There were high fixed costs in setting up appropriate product infrastructure due to the large scale of early telecommunications infrastructure. For example, making each telephone switchboard operator efficient required them to have access to enough 'switches' to divert calls to the correct destination. This meant that the industry quickly became dominated by a few firms, which later became AT&T. This concentration led the government to break AT&T into several companies through a series of antitrust actions in the 1980s (Robinson, 1988).

3.4.2 The Internet

Step 1 Newspapers exhibit natural scale and scope economies. This comes from two sources. First, the physical process of printing newspapers means that the marginal cost per printed newspaper naturally decreases with scale. Second, writing good stories is expensive and requires resources. Therefore, there are natural economies of scope that come from being able to spread the same journalistic talent across more physical copies of a newspaper.

As a consequence, newspaper markets are concentrated. This can be seen in the rise of the Hearst corporation in the early 20th century, and the rise of the Murdoch news corporation in the late 20th century.

Step 2 The internet itself and its role in disemminating news are a useful example of this process. The internet's prototype was developed by the US Department of Defense in the 1960s.[14] The project was designed to be a decentralized network, with the goal of preventing a single point of failure. The initial attraction of the internet was that it allowed masses of information to be cheaply accessible to the general public. This allowed people across to the globe to view, share and

[14] Source: https://www.britannica.com/topic/ARPANET [Accessed 9/25/2023]

create information on a global scale, bypassing centralized publishers such as the traditional newspaper industry.

Step 3 As documented in Chiou and Tucker (2017), the creation of an abundance of information actually led to a growing need for curation and selective attention from consumers. This meant that as consumer tried to find appropriately curated news or information, they actually relied more on media properties they viewed as high-quality, such as the New York Times or Washington Post, and were less likely to rely on middle-tier media properties such as local or regional papers.

3.4.3 Digital Music Content

Step 1 Typically the music industry has been concentrated in the hands of a few major labels. This traditionally reflected economies of scale and scope. First, the physical production of music (whether in the form of vinyl, cassettes or CDs) had natural economies of scope, meaning that the marginal costs of each ‘record’ sharply declined with volume. Second, talent sourcing has high fixed costs, meaning that it is more efficient for a few publishers to operate in the industry.

Step 2 In the 2000s, however, the structural advantage of the major publishers in the music industry swiftly disappeared. The advent of Peer-to-Peer (peer-to-peer) technologies in the early 2000s, such as Napster and BitTorrent, was explicitly designed to decentralize the interaction and distribution of content among users without relying on centralized publishers.

Step 3 However, the music industry started a resurgence due to the emergence of new forms of musical distribution, namely streaming services that allowed for curation and better indexing and recommendations, and also a way of protecting users from legal challenges. However, curation, indexing, and legal compliance also lead to large fixed costs, which in turn lead back to scale economies. For example, the Musical Genome project at Pandora, which tried to map back music to certain genotypes, was a costly endeavor only made possible because Pandora had enough listeners to share the benefits (and costs) of this indexing.

Another force for centralization was that the lack of accountability in decentralized systems also caused legal challenges. Specifically, peer-to-peer networks experienced a large amount of unauthorized sharing of copyrighted content, leading to many lawsuits. These challenges are inherent to the nature of peer-to-peer platforms due to their lack of centralized control (Krishnan et al., 2003).

In comparison, larger companies, such as Apple Music and Spotify recognized the importance of IP laws, and have dedicated legal teams and resources to comply with the laws and secure licensing agreements with artists. The ability of these big firms to navigate the complex landscape of IP laws is important for trust to exist within these ecosystem but also represents a large fixed cost that leads to scale economies.

4 The Tension Between Decentralization and New Technologies such as AI

The advent of generative Artificial Intelligence (AI), and in particular, the release of ChatGPT in November 2022 OpenAI (2023), has resparked public interest in AI. Since the release, we have seen hype-driven attempts to combine AI with blockchain. Despite these attempts, however, we argue that there is a fundamental tension between these two technologies which comes from the opposing natures of the two technologies. Specifically, AI emphasizes algorithms, which are almost always proprietary and are centrally controlled by a few large firms. Blockchain, on the other hand, emphasizes decentralization of the power of decision-making. In this section, after a brief review of AI, we explain this tension in more detail and discuss ways of integrating AI with blockchain.

4.1 The underlying economics of Artificial Intelligence

The term "artificial intelligence" was created in the 1950s by a series of prominent computer scientists who organized the Dartmouth Workshop (McCarthy et al., 2006). It wasn't until the 1990s and the 2000s that the field of AI received much more attention from the increasing popularity of deep learning, which became possible thanks to increased computational power through parallel computing. More recently in 2022, the advent of generative AI models, such as large language models (LLMs) that could generate human-like conversations, has created even more hype about AI.

Despite AI's different forms, at its core, the technology is about predicting some outputs based on certain inputs (Agrawal et al., 2018, 2019). For example, LLMs, such as BERT (Bidirectional Encoder Representations from Transformers) and GPT (Generative Pre-trained Transformer), are trained from massive amount of text on the internet, and are able to predict the next words given users' inputted query and the current context in terms of a sequence of generated words.

The higher prediction accuracy at a lower cost enabled by AI can complement human beings in various capacities. In particular, AI can automate tasks with patterns, like copyediting, coding, among other tasks (Eloundou et al., 2023; Felten et al., 2023; Hui et al., 2023; Liu et al., 2023). Automation could also complement human beings in performing various tasks (Luo et al., 2019; Noy and Zhang, 2023; Brynjolfsson et al., 2023; van Inwegen et al., 2023), allowing us to focus on higher-order tasks like creating new ideas and critically evaluating content, rather than routine coding tasks or correcting grammar (Luo et al., 2021; Jia et al., 2023).

AI can also complement humans by optimizing processes. One notable example is supply chain logistics, where AI has been used to forecast demand, suggesting the most efficient transportation routing, for quality control purposes. The highly scalable nature of AI systems has drastically increased the efficiency in supply chain management. There are countless examples, such as in the retail, manufacturing, financial, and healthcare sectors, where AI can be used to improve decision making by providing real time complementary services. Because of the wide applicability of AI, it is referred to as a general purpose technology, and it could have profound implications for economic efficiency (Brynjolfsson and Mitchell, 2017; Brynjolfsson et al., 2019; Agrawal et al., 2019).

4.2 Why is there an inherent tension between AI and decentralization

Though AI can greatly increase economic efficiency, it is the opposite of decentralization in almost all major aspects. AI systems are almost always centralized, as they are often developed, owned, and maintained by single firms. More specifically, the algorithm is often owned by a single firm as it is the intellectual property of the firm. In addition to having a proprietary algorithm, it typically runs on centralized servers, which are also owned (or rented exclusively) by the same firm.

In the case of AI centralized decision making can be more efficient due to economies of scale. A single firm can use a centralized computing infrastructure to train its AI models efficiently. Centralization implies that transaction costs related to negotiating the use of computation facilities are virtually zero and there is no cost of coordinating the use of computational resources. Additionally, training AI models involves much data processing. For example, recent LLMs have trillions of parameters and require a gigantic amount of data to train.[15] As a result, training is easier and faster when data comes from a few central servers, using a central algorithm.

It is also the case that because of the potential sensitivity of their output (Cowgill et al., 2020) artificial intelligence needs coordination to ensure that algorithms do not make predictions that are offensive or inadvertently perpetute social inequality. For example, the governance and regulation of AI systems is hard because undesirable outcomes from AI systems can be either due to bad algorithms or simply due to economic forces (Lambrecht and Tucker, 2019). There are many

[15] Source: `https://www.nytimes.com/2023/03/15/technology/gpt-4-artificial-intelligence-openai.html`[Accessed 9/25/2023]

issues of AI algorithms, such as algorithmic bias, feedback loops, and the lack of interpretabilityl. Ultimately, we suspect that this may one of the primary centralizing forces underlying the deployment of AI. Furthermore, there is the risk of regulation in both the USA and Europe which will shape what are acceptable uses of AI, in a way that requires the need for dynamic adaptability.

4.3 Can we use blockchain to offer the benefits of decentralization to AI?

Given that AI at its heart is a centralized technology, and blockchain is designed for decentralization the combination of the two technologies is not obvious. In this section we discuss the extent to which blockchain and the promise of decentralization can aid the centralized tendencies of AI.

4.3.1 Using blockchain to reduce vulnerability of AI to a perception of lack of fairness

As discussed in Section 2.2.1, blockchain can increase the perception of fairness in the system by clearly defining asset ownership and tracks its usage. For example, AI systems can be controlled by Decentralized Autonomous Organization (DAOs), instead of relying on centralized governance by a few big technology companies (Rossi et al., 2019). A DAO is essentially a collection of smart contracts that specify rules governing the AI system, including how different decisions in the systems are made. These rules are all transparent on the blockchain, and can only be changed based on some voting mechanisms, such the majority rule, specified in the system protocol. Using DAOs could further improve perceived fairness.

4.3.2 Using blockchain to reduce vulnerability of AI to a single point of failure

One risk of the progress of AI is that we are vulnerable to the failure of the system that supports AI. We suggest that the properties of blockchain discussed in Section 2.2.2 can actually be used to set up a more robust infrastructure that makes firms and society less vulnerable to any single point of failure.

4.3.3 Using blockchain to increase transparency in AI

The lack of transparency in AI is attracting an increasing amount of public attention: the public does not know where the training data comes from, how the data is used in decision making, how AI systems are governed, and whether they comply with regulations (Mazzucato et al., 2023). The use of blockchain technology could increase transparency on all these fronts. Therefore, transparency of the algorithm through the blockchain can increase the clarity of the nature of the problems among regulators. Having a vibrant open source community on AI can accelerate development and innovation in this field. Blockchain can contribute to open source AI in several ways. By its very nature, the blockchain is a decentralized platform without any gatekeeper. As a result, contributors around the world can collaborate on open-source projects using blockchain. The ability to define intellectual properties, track their usage and automatically receive compensation can shape incentives for innovation among users.

5 A Checklist for Managers

As discussed in Section 3, centralization can increase economic efficiency through achieving economies of scale and reducing transaction costs and coordination costs. Decentralization has a different set of values, as it increases fairness, security, and transparency in a system. Similar to many important economics questions, there is no one-size-fits-all solutions when it comes to whether to decentralize, as the optimal level of decentralization is always context dependent. Therefore, the more relevant question seems to be: what is the price that system participants are willing to pay to achieve more (or less) decentralization. In other words, system participants as a whole need to figure out when and where decentralization makes sense. Below we provide a general guideline on the characteristics of these scenarios.

First, the scenario must involve digital assets. This is because all desirable features of the blockchain, such as security, transparency and immutability, apply to only on-chain data. There is no such guarantee for data coming from off the blockchain. This is because, even if the off-chain data is authentic, parties that are responsible for transferring it to the blockchain may have incentives for fake reporting. For example, the use of blockchain to fight counterfeit physical products, such as luxury brands and expensive alcohol, has not been very successful because there is no good, decentralized mechanism to verify whether agents who put a digital authenticity certificate on the blockchain have swapped authentic products with counterfeits before certifying them.

Second, we want to decentralize in scenarios where the value of decentralization is high. These are scenarios where distributing power is vital. For example, in financial systems, a few large firms hold most of the power. This concentration leads to high vulnerability to a single point of failure. A famous example is the financial fiasco in 2008, in which large banks holding large amounts of subprime assets failed. Another prominent scenario is in the context of news outlets and democracy. Specifically, we want journalism to be independent and highly resistant to censorship. The power of these outlets should be dispersed so that information is not controlled by just a few entities, and cannot be easily censored by the government. This is critical for any meaningful form of democracy.

Third, we want to decentralize in scenarios where the costs of not having centralization is low, namely scenarios where transaction costs, coordination cost, and diseconomies of scale are not severe. For example, for authenticating and verifying asset ownership, the value of having a centralized intermediary is to establish trust in its certified ownership. There is little value in terms of reducing coordination costs in this scenario. This trust-establishing function can be achieved with a blockchain-based technology called NFT (Non-Fungible Tokens), which creates a permanent and immutable record of ownership of a digital asset. In addition to proof of ownership, all future verification and disputes related to the ownership can be handled automatically by smart contracts. Therefore, the cost of not having a centralized authority in this case is minimal. Another example is simple transfers of money or digital currencies. The goal here is to have two parties to agree on transfers, and have these agreements securely logged. The blockchain technology can record these transactions on the blockchain based on the agreement of the parties based on some pre-specified algorithms written in smart contracts.

5.1 What does this mean for product design?

When managers decide whether to use decentralization technologies like the blockchain for their products, they should keep in mind the three principles discussed above: whether their core product is digital, the value of decentralization, and the cost of not having centralized control. Below, we provide a few examples using these three principles.

The first example is a digital art marketplace that allows artists to create, license, and sell their art pieces. Since the arts in this marketplace are digital, NFT technology can be readily used to guarantee the uniqueness and authenticity of each piece of art. The value of decentralization for product ownership and licensing is high because it prevents a single point of failure of centralized platforms (e.g., from hackers who may steal the "password" and claim ownership of an art themselves), and the use of smart contracts allow artists to track how their arts are used and get compensated accordingly. The cost of not having centralization is small, as the goal does not involve coordination and the NFT technology is quite scalable. More generally, for these reasons, blockchain technology can easily add value to creative markets (Malik et al., 2023).

A second example is collaborative platforms for design. These platforms are digital in nature. Decentralization brings large values because it allows multiple designers to work together on a project without worrying about being censored on controversial projects. The decentralized nature allows every contributors' voice to be heard. The cost of not having centralization is not very large (subject to the caveat that we discuss in the next paragraph), because all the rules of collaboration can be written in the smart contracts governing the platforms.

A third example is social media platforms. Content on social media platforms is digital. There is a high value of decentralization because freedom of speech is protected by the system protocol, instead of being at the discretion of the platform owners. Users can be rewarded by system tokens for posting popular content in a decentralized fashion specified in the rules of the platform. The platform can also adopt decentralized governance, relying on the community for content moderation, instead of relying on a central authority to moderate content. However, content moderation can get tricky when it comes to things like hate speech: since no one has absolute control of contents on decentralized platforms, it may take a long time before such content is taken down, if it is ever taken down. Therefore, regulators and society need to make judgement calls about the level of decentralization on social media platforms, which at the high level trades off freedom of speech and control. Depending on this decision, the use of decentralization technologies on social media platforms may make more or less sense.

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