Chapter 2

Market Quality Approach to IoT Data on Blockchain Big Data

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1 Introduction

The Internet of things (IoT) is considered a key driving force of what the Japanese government refers to as Society 5.0, the image of an ideal future society that the Japanese government currently advocates.¹ Society 5.0 is defined as “a human-centered society that balances economic advancement with the resolution of social problems by a system that integrates cyberspace and physical space.” According to the government, “In Society 5.0, a huge amount of information from sensors in physical space is accumulated in cyberspace. In cyberspace, this big data is analyzed by artificial intelligence (AI), and the analysis results are fed back to humans in physical space in various forms.” The IoT provides a crucial link between cyberspace and physical space.

¹For details, see “From Industry 4.0 to Society 5.0: the big societal transformation plan of Japan,” i-SCOOP (see <https://www.i-scoop.eu/industry-4-0-society-5-0/>). Also see http://www8.cao.go.jp/cstp/english/society5_0/index.html and <https://www.weforum.org/agenda/2018/07/could-japan-become-a-role-model-for-the-fourth-industrial-revolution/>.

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Few would disagree that a tight-knit IoT-based society is just around the corner. However, this does not imply that a “human-centered” smart society like that envisioned by Society 5.0 will be realized automatically.

To obtain Society 5.0, it is necessary to build a new ecosystem in which data collected through the IoT can be utilized in an efficient and fair manner through high quality markets.² Many worry about the possibility that a large number of jobs could be lost to AI (see Acemoglu and Restrepo 2018; Yano and Furukawa 2019), including the eminent physicist Stephen Hawking, and some even argue that someday humans will be controlled by AI (see Kharpal 2017). Although these worries may reflect the irrational fear of a poorly understood technology that could drastically change our society, there is a more immediate concern that may underlie this fear.

That concern is the mishandling and misappropriation of big data, which many people perceive to be posing a serious threat to the present society. For example, the recent Cambridge Analytica scandal has revealed that the phishing and mishandling of personal data that are collected digitally through a social media company such as Facebook may pose a grave threat to modern society by polarizing people’s views on sociopolitical issues.³ Unless these challenges are overcome, the human-centered smart society can never be realized.

It is our view that these problems have emerged because the ownership of data collected through the Internet is not clearly defined. As a result, a seemingly unlimited volume of data is collected freely by large Internet companies. The Cambridge Analytica case suggests that such data can be easily abused.

This study demonstrates that blockchain is a key to achieving Society 5.0 by creating a high quality market for IoT big data, in which data are used both efficiently and fairly. The obstacles standing in front of this goal stem from a lack of proper ownership of big data generated through the IoT.

Blockchain is a perfect mechanism to record the ownership of scarce resources. This is because blockchain is a ledger; as Webster (1961) explains, a ledger is “a book of permanent record.” It was initially developed to create a secure, decentralized digital record on the Internet to keep track of ownership of credits and debts and their changes over time. If blockchain can make a secure record for the ownership of IoT big data, a question remains as to who should own IoT big data: the immediate party who generated the data, or that who collected the data?

As shown below, market quality theory implies that it is desirable to assign the ownership of IoT big data to the immediate party who generated the data rather than that who collected the data. That would prevent the development of large data monopolies, thereby making it possible to utilize economically valuable IoT big data in a more efficient and fairer manner.

²The concept of fairness here is that developed by Yano’s market quality theory (Yano 2009, 2017, 2019).

³According to a recent *Guardian* article (Cadwalladr 2018), Cambridge Analytica illegally created psychological profiles of 230 million Americans, which it used to influence various elections, including the 2016 Brexit referendum and the 2016 U.S. Presidential election.

To handle IoT big data in a blockchain, it is necessary to have a new blockchain on which smart contracts can be executed. A smart contract is a computer program that executes software commands in the way in which the smart contract stipulates for each contingency. It therefore minimizes the cost of dispute resolutions that a usual contract would have to bear; in the case of a standard contract, a dispute is usually resolved by a court. This, however, does not imply that a blockchain eliminates all possible disputes; those that cannot be resolved within a blockchain system must be resolved in the light of relevant laws to ensure the operational viability and quality of an IoT data market.

In what follows, we explain the uses of IoT in Sect. 2. Section 3 shows that IoT big data are underutilized due to data security concerns and data monopoly. In Sect. 4, we explain that blockchain could alleviate these problems by assigning the ownership of IoT big data to the individuals who create data through their daily activities. Section 5 explains market quality theory, which gives an analytical basis for this chapter. In Sect. 6, we explain from the viewpoint of market quality theory why the ownership of IoT big data should be assigned to the individual data producers but not to the platform companies that collect data. Section 6 also covers potential issues that IoT blockchains may face in the future.

2 IoT in Society 5.0

IoT connects cyberspace and physical space, providing the foundation for Society 5.0. Society 5.0, pushed by the Japanese government's Fifth Science and Technology Basic Plan (2016–2020), refers to an image of a near-future society in which cyberspace (virtual space) and physical space (real space) are completely integrated. It is perceived as the upgrade of the previous version of a society, Society 4.0, in which "people would access a cloud service (databases) in cyberspace via the Internet and search for, retrieve, and analyze information or data." Society 5.0 envisions a society that will come out of the Fourth Industrial Revolution, in which a large volume of data (big data) can be made available via the Internet with the use of sensors attached to objects in physical space and will accumulate in cyberspace. In cyberspace, in turn, the data will be analyzed by AI, and the resulting data will be fed back to humans.

IoT is a network of physical components such as devices, tools, machines, home appliances, and even people that are connected via the Internet to one another. Sensors are attached to each of those components; data collected by sensors can be accessed through the Internet.

People are also a part of the IoT network through smart phones. Everyone who owns a smartphone is digitally coded by a telephone number. A variety of applications are incorporated into a smartphone, creating huge volumes of personal data. For example, people use the iPhone camera to take pictures not just for fun but also for records and analyses; most repairmen use smartphones to take pictures of what they are supposed to fix. This information is sent not only to their offices but also to

parts manufacturers, who can analyze the problem to come up with proper solutions. This is precisely what IoT is supposed to achieve: the collection of data via sensors integrated inside devices (camera in the above example), communication of the data through the Internet, analysis of the data as required, and identification of suitable solutions.

Humans are attached to many other IoT sensors. Pedometers, which are used to count the number of steps that a person makes by walking, are now equipped with rather sophisticated sensors. They not only record the number of steps but also monitor physical motion, heart beat, calories burnt, and even how one sleeps—REM, light, deep sleep, and awake periods. These data are communicated to the manufacturers, who analyze the data and then provide various pieces of advice for you to live a healthier life.

IoT is used for more serious situations as well. In every corner of a city, we see automated external defibrillators, which externally administer electric shocks to one's heart to eliminate life-threatening fibrillations. This device is now put into pacemakers that are implanted in patients with serious cardiac conditions; whenever fibrillations occur, the pacemaker catches the signal and gives internal electric shocks to the heart to realign the heartbeat. At every moment, data can be collected by the pacemaker and sent through the Internet to doctors and manufacturers who constantly monitor the patients and their pacemakers.⁴

IoT is also important for taking care of people who need assistance from others; as the society becomes wealthier, the importance of care for the elderly, child care, and patient care will increase. Alzheimer's patients who lose short-term memory need assistance with cognitively demanding tasks. For example, they are more likely to forget simple tasks that can have consequences for health and safety, particularly related to cooking. Such scenarios have always required the constant supervision of a relative or carer. IoT devices will be able to replace some of these human chores. A house can be wired to the Internet with motion sensors, which can track movement in the different rooms and areas of the house. With these sensors, families and health service companies can monitor when the patient wakes up, goes to the kitchen, and so on.

Perhaps one of the most important industrial applications of IoT may be in the agricultural sector. The IoT provides a new method of agricultural production. Sensors can be attached to livestock to collect health and growth data through the Internet, which can be used to control the administration of feed and medicine. Every square meter of farmland can be monitored by sensors that collect agricultural data, for example, soil moisture, fertilizer density, sunshine, temperature, and so on, and send them through either wireless or wired networks to a control center. The control center can then analyze data and optimize the use of agricultural input to external environments. This application of IoT can optimize the use and cost of expensive fertilizer and pesticide, because the IoT sensors can detect exactly which parts of the field, and how much, plants need to be fertilized or treated with pesticides. Agriculture is

⁴In many cases, data from a pacemaker is first sent via a smartphone to a base station for security reasons. One can imagine what could happen if a pacemaker network were overtaken by individuals with malicious intent.

highly water intensive. When water is supplied by sprinklers, a significant portion of water never reaches the plants because of evaporation. The use of IoT to monitor the soil moisture and to optimize the water supply to each small area of farmland would greatly economize water usage. This capability will become increasingly important as global warming continues.

Another important application of IoT relates to cars, particularly for the development of self-driving cars, which simply could not function without IoT. Self-driving cars use many sensors, including high-quality radars and cameras, to map out the car's surroundings. The IoT system processes the feedback from the sensors, calculates a path to take, and gives directions to the car's controls. Cars are equipped with mechanisms to avoid obstacles, obey traffic rules, and minimize damage in case of an unavoidable accident. While we may have to wait a long time before driverless cars become widely used, there are more immediate applications of IoT in cars. It can collect data on the working status of various vital parts of cars, which can then be analyzed to contribute to safer driving. IoT can also gather information on driving habits and analyze data for safer driving, and could provide vital risk information to insurance companies.

The Japanese government designated Society 5.0 as a national goal, creating a society where "people, things, and systems are all connected in cyberspace and optimal results obtained by AI exceeding the capabilities of humans are fed back to physical space. This process brings new value to industry and society in ways not previously possible." To achieve this goal, as discussed below, it is highly important to fully utilize data collected in the IoT space.

All economists would agree that the best way to make efficient use of scarce resources is to rely on the market. IoT data is no exception. It has been known in economics that the establishment of private ownership for resources is a prerequisite for the development of a market for those resources (see Coase 1960). In reality, however, the ownership of data collected via the Internet has not yet been clearly established. Yano's market quality theory implies that Society 5.0 would be unrealizable without high-quality markets (see Yano 2009). Although healthy competitive environments are a prerequisite for a high-quality market, data produced through Internet transactions are currently monopolized by a few gigantic Internet companies, including Google, Amazon, and Facebook. As we discuss below, new types of blockchain may break data monopoly and bring the economic use of data into a competitive environment.

3 IoT Big Data: Underutilization, Unfairness, and Inefficiency

As we watch science fiction movies, we see a future filled with autonomous devices flying around, doing things on their own accord, and constantly trading information

and data. That is a great vision. The sad truth is, however, that we are still very far from such a future.

The IoT space has not really moved forward in substantive ways, at least not in the past one or two decades. IoT investments today largely consist of infrastructural hardware and software, but what really makes IoT valuable is the enormous amount of data they collect. If the data cannot be effectively utilized, the devices and the infrastructure are useless and their investment is unjustifiable. As of this writing, only a small sliver of data is actually being put to use, while the rest languish in data silos. Only when we start taking full advantage of this data can we truly realize the potential of IoT.

Application discovery has always been difficult, which is why healthy ecosystems require the broadest participation possible to maximize the chances of discovering viable applications. IoT systems, on the other hand, are invariably closed, as manufacturers, systems integrators, and owners of these systems build up layers upon layers of walled gardens denying access to their data, despite the fact that the data is not close to being fully leveraged or monetized.

Hence, one of the most fundamental challenges facing the IoT space today is the lack of sharing and trading of IoT data. Without it, broad participation cannot be achieved, and data will remain fragmented and useless. But why is it so hard to trade data or to share data? As we discuss below, this may be attributed to two factors: data security and data monopolization.

3.1 Data Security Issues

Why is IoT big data not fully utilized? The first reason relates to data security and privacy concerns, where people are afraid that they will be unfairly treated. If data is lost or stolen, devices can be compromised and secret information could be leaked.

The second reason is driven by business and economic considerations. Why should this data be collected? How could money be made from this data? If no compelling business goals or business models can be articulated, there will be no way to persuade people or companies to make investments. The problem of high cost must also be considered. The cost of IoT is not just incurred in the purchase of a sensor. It includes the connectivity cost, the storage cost, and the analytics cost. There are many hidden costs involved with IoT, and if the investment cannot be justified with reasonable returns, the investment will not be made.

A third reason for a lack of data utilization is insufficient internal expertise, which creates a fear of vendor lock-in. Because most companies do not really have the expertise to analyze data, they tend to outsource the task to a third party. However, companies may also have concerns for their own privacy; sharing data with an external platform or vendor not only reveals information to outsiders, but the company may also become overly reliant upon these external partners, leading to loss of control and potentially creating new competitors. Such sentiments are strong, which further prevents companies from sharing data.

As discussed above, blockchain technology is designed to provide secure records and permissions. It is therefore expected to greatly reduce the mishandling and monopolization of big data, which many people perceive as posing a serious threat to the society.

As news of problems like the Cambridge Analytica scandal spread, more and more people are turning to blockchain, which makes it possible to share and distribute data in a secure fashion. For example, IBM has introduced an IoT blockchain service, which makes it possible “to send data to private blockchain ledgers for inclusion in shared transactions with tamper-resistant records.”⁵ However, the problem cannot be fully resolved by ensuring just data security.

3.2 Data Monopoly Issues

The monopolization of big data by the large platform companies presents challenges to effective data utilization. Some fear a serious threat to democracy, bringing the digital economy to a “winner-takes-all arena, with a small number of companies controlling large parts of the market” (Cerf et al. 2018). Such a consideration is said to underlie the recent adoption of the General Data Protection Regulation of the EU (Cable 2018). Khan (2016) argues that platform companies like Amazon exploit their scope to engage in predatory pricing; according to a recent article in the *New York Times*, her argument has been well received among policymakers and has started to influence antitrust laws.⁶

The fundamental reason why data monopolies have formed in the recent economy is the lack of proper data ownership. This is no surprise given that big data did not even exist until very recently. Except for very limited types of data, there had been no way to either collect or use data.

To consider how personal data has been used in commerce in the past, suppose that you have just purchased Karl Marx’s classic book *Das Kapital* at your local book store. From this piece of data, the book store can deduce that you are likely to be an economist. You are probably liberal in the political spectrum and highly educated (the book is rather difficult to read). A single piece of data like this is therefore useful for a bookstore to give a personalized advice and recommendations to a customer. This used to be the type of service that local book stores provided years ago. The economic value of that piece of data was so small that no one tried to claim the ownership; it is safe to assume that such data were implicitly co-owned by bookstores and their customers.

The Internet has completely changed the nature of personal data of this sort; online vendors can now collect extremely large volumes of data with minimal cost. Such data are highly valuable because many different statistical predictions can be

⁵See <https://www.ibm.com/Internet-of-things/spotlight/blockchain>.

⁶Also see the *New York Times* article introducing Khan’s work (Streitfeld 2018).

made with respect to different groups of people; one example is the way in which Cambridge Analytica has used stolen data.⁷

As a result, gigantic data monopolies have been created in which the ownership has been claimed by default as data accumulate in the server. This has occurred even before the society can agree on who owns Internet data, which has perhaps contributed to the current sentiment against big data monopolies.

4 Decentralization: Towards Fair and Efficient Use

Perhaps the most important innovation that blockchain can bring into IoT space is the distributed ownership of data created by the IoT. Through blockchain technology, all data generated by IoT devices can be encrypted. Each piece of encrypted data can be signed by the private key of the device that generates that piece of data. This means that blockchain technology makes it possible for the owner of the device generating a particular piece of data to own that very piece.

As discussed below, blockchain could greatly alleviate the unfair and inefficient utilization of big data by assigning the ownership of each single piece of data generated by the IoT to the person who generates the data. In expanding the IoT, smart-phones will play an important role as IoT devices in collecting big data. To assign decentralized private ownership and put it to widespread use, a new blockchain needs to be developed that is tailored to the decentralization of IoT data ownership.

4.1 *Unfair Data Monopoly*

Right now, more and more people feel that big data are unfairly collected. To see people's frustrations, it is useful to digress briefly and consider the social media industry, which is one generation older than the IoT big data industry. Reflecting their feeling of unfairness, people have started developing social media networks based on blockchain.

Information is free. It creates invaluable external benefits to society. This is the general perception that has greatly helped the development of social media companies. People are connected to their friends from totally different regions of the world through social media; a lot of personal information from different parts of the world is exchanged instantaneously. Active interactions of people helps to deepen their mutual understanding and even the cross-cultural understanding of each other. This brings the world closer and helps to create a more human-centered, friendly society.

Such network externality-based considerations have long supported the development of social media services. However, as several social media companies have

⁷In the recent literature, it has been established that people's opinions and views can be critically influenced by the way in which information is presented. For example, see Horiuchi and Ono (2018).

grown into huge network platform monopolies, many people have started to question the ethics of such data monopolies.

Why do people willingly give up their personal data to large social media companies, which can use the data in anyway they want to make profits? This appears quite unfair. As the Cambridge Analytica scandal shows, this practice can lead to the misappropriation of personal data. That is undoubtedly a dirty trick, so it is not surprising that a large number of people are bothered by unfair operational protocols that social media companies like to enforce.

This change reflects a change in the nature of a monopolistic market, as network platform monopolies grow. In the market, multiple network platform companies compete with one another. However, the information and data that a particular company has collected is now locked into that company, which can act as a monopoly with entry barriers made up of its data. This has resulted in a new monopolistic market that appears to be completely different from conventional monopolistic market like the late 19th century oil industry, which was dominated by Standard Oil. In the oil market, the products traded are uniform, whereas in the present network platform market, each platform company offers its own unique service.

A similar market structure is called monopolistic competition in economics. Under monopolistic competition, as in the market for wine, many companies supply their own unique differentiated products in competition. Dominated by far fewer and much larger network platform companies, the social media market differs from a typical monopolistically competitive market.

As noted above, blockchain technology provides a way to challenge such a data monopoly. An Ethereum-based platform called Indorse (<https://indorse.io/>) is a good example.

Indorse is a social media network for IT professionals, which adopts a decentralized consensus mechanism. That is, in submitting the portfolio of one's professional skills, it is evaluated by other random professionals in the network. When an individual uses the site, he/she is asked to choose his/her skills from JavaScript, Java, Solidity, Python, and C#. The submission is then evaluated by others and published on the Indorse network in a secure manner. Anyone who submits personal data for skills evaluation will receive some units of token that can be used for services like advertising and company pages with validated connections. Indorse explains that in this way, the cost of professional accreditation can be economized, that the lack of skillful evaluators for emerging and soft skills can be alleviated, and that possible bias and fraud that may occur with professional accreditation can be minimized.

4.2 Inefficient Use of IoT Big Data

Blockchain can ameliorate the underutilization of big data in many ways. First, it is based on a decentralized operating model. Because it is a decentralized network, users are not dependent upon any single entity. Everyone runs his/her own

node.⁸ Thus, everyone can be independent, which prevents data monopoly. Everyone is decentralized. Thus, no one is being locked into any one platform or set of infrastructures.

Second, blockchain could significantly lower a rather high entry barrier into the network platform industry. There are several factors that makes it difficult for newcomers to compete against established big companies. Think of YouTube, for example. The first issue is the brand. Everyone knows, uses, and likes YouTube. Many people watch it almost habitually. Once people start accepting a particular service at that level, a brand name is established, which is one layer of competitive advantage. The second factor is the data and algorithms that form a virtuous cycle that allows YouTube to become increasingly accurate in their content categorization, targeting, and advertising. The third is the infrastructure that the company has built. It has servers, it has technology, and it has negotiated great contracts with Internet service providers to make sure it enjoys prioritized traffic routing. All of this established infrastructure is difficult to replicate. Even if someone were to spend billions of dollars to replicate it, one could fail easily. Blockchain significantly weakens the second and third parts of the competitive barrier by decentralizing the data, algorithms, and eventually the hardware infrastructure, turning them into commodities accessible by anyone. As Yano (2019) shows, one source of market power is the bundling of commodities. If someone can bundle up commodities into a big chunk, they can exercise bargaining power over trading partners and force them to accept unfavorable terms of trade. As discussed above, that is precisely what is happening in the current data market.

Third, blockchain fractionalizes resources into pieces, which could drastically increase the number of people who participate in the IoT big data market. Data will become increasingly open-source, which removes the intellectual property barrier. Storage, processing power, and connectivity are all fractionalized, and can be used on a decentralized network. If that is achieved, anybody will be able to replicate the structure of entities like YouTube over night. Then, the existing brand barrier will also be reduced. Many different products will be tested on the market and those that are deemed truly valuable will be accepted as new brands. Of course, existing brands like YouTube can compete with these new products; if they prove valuable, they will remain in the market.

Fourth, blockchain would stimulate big data usage by enabling each individual to sell data that he/she generates at the same time to buy data that he/she needs. Right now, except for a few data monopolies, everyone has to participate in the big data market as a buyer even though he/she is also a producer of data. The decentralization of data ownership would lead to a perfectly competitive market for big data in which everyone can participate in data transactions in two ways: as a seller of the data he/she produces and as a buyer of the data that others produce. In a society in which cyberspace and physical space are integrated, everyone would become a supplier of data at the same time that he/she could act as a demander of data. If blockchain

⁸A node implies a participant on the network. Often it is an Internet/computer account through which one obtains access to a network as well as keeping a local copy of the entire network data.

would make it possible to create a market in which all sorts of data are traded, the data usage would become much more efficient than in the market where everyone has to participate as a buyer except a few data monopolists, who can manipulate the types of data to supply. In history, many mechanisms have been developed that make it possible for people to share ownership of an asset: corporate stocks and bonds, securitization of debts and other obligations, time-share of a second house, and rental cars. These mechanisms all help to utilize resources more efficiently. As discussed above, blockchain is one such mechanism that enables sharing small pieces of data. This provides an important way to challenge data monopolies owned by large platform companies and to promote more efficient usage of data where anyone can participate.

Fifth, the use of blockchain to decentralize data ownership would promote technological innovations, which cannot be expected from monopolies. Although an enormous volume of data has been accumulated at big platform companies, it is likely that much of the data has not been utilized. This is because it is beyond a single entity's capability to understand the full spectrum of all potential applications in the world. For a large company with a great deal of data, it is typical to acquire external expertise through requests for proposal. However, even if a company employs external resources, it is still unlikely that they can cover the full spectrum all possible applications. This is why a decentralized network where any entity can participate will effectively and hugely expand the amount of external expertise that any single entity can access.

More broadly, the idea of involving external resources by a decentralized network relates to open-source and open-innovation initiatives, which are pushed forward by many policymakers all over the world.⁹ Many people say that because they cannot find a business case for this data, they are not going to use it. If, however, data are released to an open community, it is certain that some will figure out what to do with it.

Because blockchain is a public ledger on a decentralized open network, anyone can join. This implies that blockchain encourages competition. In the future data market, the idea of competitive advantage will become much less important. Competition will become much fairer and will occur on an equal footing.

4.3 Decentralized Creation

To build a blockchain for an IoT network, smartphones are expected to play an important role. To this end, Apple has made a big contribution to the decentralization of data by allowing all data that is being generated by iPhone, an IoT device, to be released to the public. Anyone can build any application on top of it, leverage the data, and leverage the device. That has made Apple hugely valuable. If Apple were to have monopolized all data, it would be worth a small fraction of what it is worth

⁹For recent issues on open innovation, see Bogers et al. (2018).

today. Because it made the conscious decision to share and open up the data created by this IoT device, iPhone and Apple have become highly valuable.

From the viewpoint of data usage, iPhone is the most successful IoT device in history. This is because of the conscious decision of Apple to open up the Apple Store, which has made iPhone hugely successful. Through iPhone, many types of data have been collected in large volumes. The device is equipped with many different sensors such as gyroscope, compass, barometer, and camera and all collect data whenever iPhone is used.

4.4 Need for a New Blockchain Protocol to Handle IoT Data

Most of the IoT data is big data, which is far beyond the scope of the original blockchain for Bitcoin. As Omote and Yano (2020) explain, the Bitcoin blockchain is designed to handle numerical data on transactions, each piece of which is rather small.

Ethereum is also unable to handle IoT big data. It is a classic linear blockchain built on the Bitcoin system. Because of this, two weak points arise. First, it is built on a wasteful system. If 10,000 nodes are generating blocks, the work of 9999 will be wasted; only one node can win. That concept is very wasteful. Second, it is very slow. Every single moment, Ethereum works on a single node in sequence; if a large number of transactions are waiting to be included in the chain, they have to line up to wait for their respective turns. These weak points can easily create a serious bottleneck for Ethereum.

For fullutilization of IoT big data, something far beyond these classic blockchains is required. The concept of concurrent smart contracts is one idea to deal with this problem.

As explained by Yano et al. (2020), “a smart contract is a computerized transaction protocol that executes the terms of a contract.” [It is supposed to] satisfy “common contractual conditions (such as payment terms, liens, confidentiality, and even enforcement), [to] minimize exceptions both malicious and accidental, and [to] minimize the need for trusted intermediaries” (Szabo 1994). The blockchain for Bitcoin can handle incomplete smart contracts only in the sense that it produces a record of payments.

A more complete smart contract adds a layer of logic on top of the Bitcoin blockchain. In this case, the smart contract is essentially a program. Ethereum adds the function of executing a complete program on top of the Bitcoin type blockchain. Ethereum adds this function to the blockchain for Bitcoin.

For example, a smart contract can incorporate a voting mechanism. Who likes this TV program? People can vote on such an issue. A smart contract can create a voting mechanism by which the results of the votes are all encoded into the blockchain. Then, the votes become immutable and fully transparent, which the classic blockchain ensures.

On Ethereum, the smart contract size is theoretically unlimited. However, it is costly to execute a smart contract on Ethereum because one has to pay to store and process smart contract s. This fee structure effectively sets an upper limit on the size of a smart contract on Ethereum, which makes it costly to write a sophisticated program (smart contract) that needs to handle IoT big data freely.

To overcome this problem, a new protocol is desirable. A “concurrent small contract” occurs when under any single node, the node is able to process hundreds of smart contract calls simultaneously. It uses theory called software transactional memory, which does speculative parallelization of smart contract costs. In the next chapter, Steven Pu explains this in detail.

5 Market Quality: Fairness and Efficiency

So far, the terms efficiency and fairness have been used without explaining their precise meaning. Efficiency is a standard economic concept, which might need no explanation; it refers to a state in which the right resources are allocated to the right places. Fairness, in contrast, is a new concept, and was introduced as competitive fairness in Yano (2008). It is a new concept of economics, and was introduced as a normative measure for the performance of a market. See Yano (2019) for precise definitions of fairness and market quality.

5.1 Market Quality Theory

Yano (2009) defines market quality as a normative measure that reflects both efficiency and competitive fairness. With this concept, Yano’s market quality theory can be summarized by the following two propositions:

First Proposition: High- quality markets are indispensable for healthy economic growth.

Second Proposition: Well-developed market infrastructure is indispensable for maintaining high-quality markets.

These two propositions are drawn from the observation that we have experienced three large and rapid technological advances, which are often referred to as industrial revolutions. These industrial revolutions resulted in significant declines in market quality. Once the disrupting effect of an industrial revolution subsided, market quality went back up, thereby leading to the next industrial revolution. This process is illustrated by the three C curves in Fig. 1 Market quality may be characterized by three different factors: the quality of competition, the quality of information, and the quality of goods. The lowering of market quality in each of the three C curves may be associated with these factors.

The First Industrial Revolution began with the invention of the steam engine in eighteenth-century England. Right after this period, the quality of the labor market

Fig. 1 Market quality dynamics

fell; it is well known that this experience led to the Marxian theory of labor exploitation (Marx 1867). As Yano (2005) shows, labor exploitation can occur when the quality of competition falls.

The Second Industrial Revolution was spread over a relatively long period. It started with the invention of the Bessemer converter for steel production in the mid-1850s, which drastically lowered the steel price and led to a construction boom of railroads, bridges, and steel ships. In the mid-1870s, the economy contracted sharply and fell into a long period of stagnation, which lasted until the early 1890s; this stagnation was so severe that it was called the Long Depression. During the period of stagnation, large monopolies, as represented by Standard Oil, developed. This was considered to have a serious negative impact on the society and led to the antitrust law of 1890 in the USA. The other technological advance during the Second Industrial Revolution was the use of electrical power during the turn of the century. This period of rapid growth ended with the Great Depression of the 1930s. The US congress perceived the Great Depression as a result of mishandling and misappropriation (or the lowering of quality) of information in securities markets, which led to the Securities Act of 1933. It is generally perceived that a lowering of the quality of information in the securities market caused the Long Depression and the Great Depression.

The technological progress that we have experienced in information and communication technology since the 1990s may be thought of as the Third Industrial Revolution, which may have been a major player in bringing about the 2008 global financial crisis; Yano (2010) explains this as a result of the lowering of the quality of securities.

5.2 *Competitive Fairness*

There is no doubt that “good markets” and “bad markets” exist in the real world. Few buyers would disagree that a good market is a market in which better products are available for a lower price. Indeed, no other answer expresses the nature of a good market quite so accurately for a buyer. If you are a seller, however, the opposite is true. In other words, from the seller’s point of view, a good market is a market in which you can sell better products for more. In general, there is a range of price that is determined by balancing the needs and desires of buyers and sellers. Unless a price is set in this range, it cannot be considered to be appropriate.

If prices are set in an appropriate range, it is often a result of competitively unfair transactions. According to the Unabridged Edition of Merriam-Webster (1961), competition is “the act or action of seeking to gain what another is seeking to gain at the same time and usually under or as if under fair or equitable rules and circumstances.” Moreover, “fair” refers to a state “conforming to an established commonly accepted code or the rules of a game or other competitive activities.” These definitions attest to the importance of fairness for a market, which cannot function without competition. The concept of market quality follows this idea.

Yano (2008, 2009) defines that market actions and activities are competitively fair (or simply fair) if they are conducted in compliance with the following fundamental rules.¹⁰

Rule 1 (private property right): Goods traded in the market must be subject to transferable private ownership.

Rule 2 (voluntary action): Transactions in the market must be voluntary.

Rule 3 (nondiscrimination):

1. Third-party individuals and direct trading partners must be treated equally.
2. Anyone can freely trade with anyone in any amount or, more broadly, on any terms.

The protection of private properties (Rule 1) is perhaps one of the most fundamental rules for a human society, which is evidenced by one of the Ten Commandments “You shall not steal.” In economics, the role of this rule has been studied extensively since the work of Coase (1960). His fundamental conclusion, known as the Coase theorem, implies that unless proper property rights are established for resources, the market for those resources cannot develop. This theorem gave a basic theoretical framework in which issues such as externalities and torts are analyzed in economic terms. The same consideration motivates the present study, focusing on the ownership of IoT big data.

The protection of voluntary actions (Rule 2) is also a basic rule that supports a civil society. In economics, the importance of this rule has been recognized since the work of Smith (1776), referring to the invisible hand. Subsequently, Smith’s theory

¹⁰Yano (2009) includes the equal treatment under rules as the fourth fundamental rule. The rules presented above follows Yano (2019).

has been elaborated by many studies including Edgeworth (1883) and Debreu and Scarf (1963).

The nondiscriminatory treatment of Rule 3 can be traced back to Chapter 41 of the Magna Carta (1215), which had influence on the early development of US property commercial codes during the American Revolution period (Hulsebosch 2016). As Yano (2008) demonstrates, the US corporate law, in particular, on mergers and acquisitions is in line with Rule 3, which is interpreted to stipulate that no one is allowed to discriminate one trading partner from another for noneconomic terms.

6 Creation of a High-Quality Big Data Market

As discussed in Sect. 4, we argue that the ownership of data should be assigned to the person who generates the data, which can be made possible by a properly designed blockchain technology. Before closing this chapter, we explain this conclusion from the viewpoint of market quality theory.

6.1 Assignment of Data Ownership

Market quality theory implies that the ownership of a scarce resource should be established in such a way that it may lead to the creation of a market with higher quality. This conclusion is an extension of the Coase theorem (Coase 1960).

The theorem implies that the market for particular resources cannot develop before the transferable ownership is established with respect to those resources. Once proper ownership is assigned, incentives for trade will be created, thereby forming a market in a decentralized manner. The working of market mechanism is neutral to the way in which the ownership is assigned if market transactions are not costly (neutrality result). If transaction costs are not negligible, the ownership should be established in such a way that a more efficient allocation can be reached in the resulting market.

As Khan (2016) points out, network platform companies like Amazon provide highly competitive services at low prices, which implies plentiful supply. In other words, the market for network platform services is rather efficient. If we assume that the IoT big data market is to develop into a similar market structure, the Coase theorem is of little use for the determination of data ownership.

Khan (2016) proposes that the antitrust law, evaluating predatory pricing, should depart from the price theory-based approach and shift back to the old structuralism, analyzing the “competitive process and market structure” (Khan 2016 p. 745). She then lists “a range of factors that give insight into the neutrality of the competitive process and the openness of the market,” [which include] entry barriers, conflicts of interest, the emergence of gatekeepers or bottlenecks, the use of and control over data, and the dynamics of bargaining power. Such a categorical approach to the antitrust law is, however, dangerous for the healthy growth of ever-changing markets such as

those for IoT big data, blockchain, and social media, which is probably why the US court has shifted away from structuralism.

6.2 Predatory Pricing and Exploitation: A Price Theory Approach

Market quality theory provides a price theoretical basis for predatory pricing and exploitation. Under the nondiscrimination rule (Rule 3), as discussed above, no one should be locked into trading with a particular trading partner. If one receives a better offer than anything from the current trading partner, he/she should be free to move to take the new offer.

As Yano (2008) demonstrates, the nondiscrimination rule ensures every market participant a surplus at least as large as that which the best outside offer (or alternative competitive offer) avails. Even if one trades with a monopoly, it should receive such a surplus, which he/she could receive if a transaction were made in a competitive environment. As Yano (2005) shows, this result gives an economic explanation to the real world cases of predatory pricing and economic exploitation, which has not been treated in the previous economic literature.¹¹

This study has pointed out several potential problems in the case in which the ownership of IoT big data is assigned to the companies that collect data. First of all, it is likely that large data monopolies like the current network platform companies would be formed. Such a monopoly could abuse monopoly power, which has been observed in social media companies. Moreover, big data might not be shared and traded efficiently in a market; underutilization of valuable data could result. All these factors reduce the quality of an IoT big data market. In short, market quality theory stipulates that the ownership of IoT big data should be assigned to those who generate data by themselves, which is made possible by blockchain technology.

6.3 Further Discussions

A market filled with contractual disputes cannot be regarded as being high quality; such disputes arise when, in a very basic sense, some of the three fundamental rules above are violated. Combined with the idea of a smart contract, blockchain technology introduces a completely new way in which social obligations are enforced. In modern society, many social obligations are enforced centrally by laws. In a smart contract, in contrast, transactions are enforced by computer algorithm, which can be

¹¹For example, see Khan (2016), who points out that under the current framework of antitrust law, which is based on efficiency, output, and prices, it is difficult to “cognize the potential harms to competition by Amazon’s dominance.”

expected to wipe out any contractual disputes. This, however, does not imply that the contractual arrangements in a blockchain are free from dispute.

There are many potential sources of dispute in the transactions of IoT big data. This may be explained by using the example of Indorse, a decentralized social media network for IT professionals. In this blockchain, a particular applicant's professional skills are evaluated by peers and securely published in the blockchain. If participants are all honest, the smart contract in the blockchain would create a valuable dataset for IT professionals, which all potential clients and employers can rely on. If, however, dishonest individuals start submitting fake portfolios, it would no longer be the case. In that case, whether a particular person's skill set posted in the blockchain network is reliable must be decided outside of the network; one obvious way to check the reliability is simply to interview a candidate before deciding to hire. If the fraction of dishonest individuals increases, even interviewing would become too costly, in which case the network itself would become useless.

A deeper problem would arise if a potential employer were to suffer significant damage or loss by employing a dishonest individual. The employer would find it difficult to claim compensation for the damage against the network, which is built in a decentralized manner with no one explicitly responsible.

From an economic viewpoint, such a problem can be expected to be eliminated in the long run because people would cease to rely on an erratic network. In the interim, however, dishonest individuals may pose a serious problem. To avoid such problems, it is important to maintain competitive fairness in the sense of market quality theory.

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Besides those rather theoretical works, Prof. Yano has also provided influential insights on contemporary real-world phenomena. Those include transfer problems (*American Economic Review*, 1999), voluntary export restraints (*International Economic Review* [IER], 1995), and trade conflicts (IER, 1998), on which there have been a number of follow-up papers.

His recent research on “market quality” addresses various problems in modern economies, including the financial market crisis since 2008 and the recent nuclear accidents in Japan, from the point of view of market quality—a new economic concept that Prof. Yano has developed and is applying to Japanese and international markets. Concerning quality of competition, quality of

information, and quality of products, market quality is defined as an index jointly determined by the efficiency of an allocation and the fairness of the prices that are achieved in a market.

Prof. Yano received a B.A. in economics from The University of Tokyo in 1971 and a Ph.D. in economics from The University of Rochester in 1981.

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