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Abstract: Blockchain-enabled cryptocurrency instruments have gradually filtered into financial intermediation, disrupting traditional institutions. This paper discusses the benefits of blockchain to household welfare, focusing on financial intermediation services (FIS). Its main aim is to highlight points of incompatibility with current institutional frameworks and outlines the greatest barriers for its widespread adoption (i.e., regulatory, technological, and environmental). To support our discussion, we develop a stylized general equilibrium model with two competing FIS technologies (i.e., traditional and blockchain). We show that removing these barriers could displace traditional institutions with blockchain technology and raise welfare. Finally, we argue that the 2022 and 2023 cryptocurrency scandals and the ongoing calls for comprehensive, cross-country, institutional changes will be remembered as a turning point in terms of serious efforts to integrate this new technology and make it more mainstream.

Key Words: Blockchain, Institutional Barriers, Fintech, Cryptocurrencies, Financial Intermediation
JEL: G21, G28, L51, 033
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1 Introduction

Until a few years ago, blockchain was an esoteric technology used by only a few initiates. Nowadays, it powers cryptocurrency and other novel financial intermediation services (FIS) and is gradually being adopted by many other sectors such as legal, healthcare and logistics. In this paper, we focus on blockchain application for fintech[1] which is where this technology has had the widest visible adoption and, so far, the greatest conflict with traditional institutional frameworks.

Blockchain disrupts traditional institutional systems and economic behavior because it eliminates the need for intermediation, introduces a decentralized and transparent framework for economic interactions, and is a general-purpose technology that could be used for a wide range of sectors (Frolov, 2020). As we discuss in more detail, blockchain uses cryptographic technology to create secure, verifiable, automated transactions and record-keeping. This reduces transaction costs, enhances trust, and improvs efficiency. The immutable nature of blockchain records also facilitates accountability and promotes adherence to institutional rules and regulations. Its decentralized nature can empower individuals and communities (Paladini et al., 2021), and potentially challenge and reshape traditional hierarchical institutional arrangements.

The trends that we present below suggest that adoption of blockchain is inevitable and has the potential to improve welfare. However, alongside its benefits, there are serious negative externalities that current institutional frameworks are protecting against and are therefore imposing barriers. The speed, extent, and the types of technology (protocols) to be chosen in the future all depend on the regulatory environment. It is therefore imperative to understand this technology and how it links with a workable framework because otherwise, this could (i) stifle the innovation and integration of superior technologies, (ii) lock us into using inferior ones, and (iii) leave a vacuum for uncoordinated unregulated development, in countries or sectors with lower quality standards, and the subsequent negative (or sub-optimal) effect on welfare.

The aim of this paper, therefore, is to outline the biggest barriers (or misalignments) for adoption of blockchain enabled services. These are: (i) institutional harmonization with existing laws and regulations,[2] (ii) technological barriers, and (iii) environmental bottlenecks. To support our analysis and show that removing these barriers could displace traditional institutions with blockchain enabled and raise welfare, we develop a stylized general equilibrium model that has two competing FIS technologies (i.e., traditional and blockchain).

In recent reviews of fintech applications and its future direction, blockchain is mentioned sparingly in Thakor (2020) and overtly in Boot et al. (2021). However, in the short time since these papers, the landscape

[1] Thakor (2020) defines Fintech as the "*use of various technologies to provide better financial services*".

[2] For example, General Data Protection Regulation (GDPR) in Europe and California Consumer Privacy Act (CCPA) in the USA.

has already changed massively. History books will remember 2021 as the year in which blockchain-enabled cryptocurrencies have become mainstream instruments for FIS, with potential to disrupt many other sectors. For example, between 2020 to 2021, the Blockchain sector attracted a staggering amount of money from big investment banks, hedge funds, and corporations (e.g., Tesla, Mastercard). Governments such as Salvador have made Bitcoin (the most well-known blockchain powered cryptocurrency) a legal currency. Other central banks are experimenting with their own variants. Within two years, the cryptocurrency market capitalization increased from only USD 100 billion to over USD 3 trillion, and Bitcoin alone passed the USD 1 trillion mark in 2021, having its price soar above USD 53,500 (CNN Business, 2021), and the technological spillover onto other sectors is obvious.

A year later[3], three scandals rocked this sector: (i) the Luna-Terra's Stablecoin collapse, (ii) the collapse of FTX, the second biggest crypto exchange that had wide-reaching implications on FIS, and recently (iii) the Silvergate's bank-run on its deposits and subsequent collapse (Milmo, 2023). These scandals plummeted the price of Bitcoin to USD 15,000 (which later stabilized at around USD 28,000 by Spring 2023) and other cryptocurrencies. Recognizing that these novel financial technologies are becoming part of the landscape and are exposing markets to such volatility risk, many institutional actors have increasingly called for a once-and-for-all central regulation of the entire blockchain-related universe (e.g., as early as Fink, 2018).

Our paper contributes to blockchain, FIS, and to institutional change in three ways: in section 2, we explain why blockchain is an inevitable breakthrough technology with intrinsic value to society. Section 3 provides a stylized conceptual model to show how blockchain could displace traditional FIS and raise social-economic welfare. Future work could use our stylized model to calibrate and apply it to specific countries and/or sectors to quantify the benefits and costs of this technology. Finally, sections 4 and 5 are the most important contribution. They provide a detailed outline and discussion of the main institutional and non-institutional obstacles that policy makers and engineers will need to overcome to safely adopt blockchain technology within FIS and beyond.

2 A background on blockchain

The origins of blockchain are found in the crypto-anarchist underground of the Internet in the 2000s, with the now-famous paper written on the pseudonym Satoshi Nakamoto (Nakamoto, 2008; Lemieux, 2013). Although the term "blockchain" was not actually used by Nakamoto's original paper on Bitcoin, it was later adopted because of the technical way the transactions are recorded and stored.

[3] Descriptive data updated for April 2023, the time of writing this article.

The system resembles a long chain of interconnected blocks, each containing the hash of the previous block (Crosby et al., 2016; Zheng et al., 2018; Casino et al., 2019). While any mathematical treatment of the principles behind the blockchain is outside the scope of our paper, we summarize the main points that make it so attractive:

1. *Not intermediated, but transactional:* Mainly based on open-source protocols and an autonomy principle in which relevant parties are independent of each other, therefore not relying on any single actor.
2. *Highly resilient network:* It is not easy to compromise the network given its intrinsic decentralized nature in which nodes are connected to other nodes, shared as a public ledger by many participants rather than through one central system (Swan, 2015; Meng et al., 2018).
3. *Secure and incorruptible:* It employs a public key infrastructure (PKI) system with both public and private encryption keys (Housley, 2004; Christidis and Devetsikiotis, 2016; Meng et al., 2018), though not without vulnerabilities (Li et al., 2017). The blockchain does not require the parties involved in the transactions to reveal their identity. Furthermore, the data saved in the blocks are incorruptible (Economist, 2015).
4. *Fosters a consensus mechanism:* It creates a new type of exchange environment that fosters consensus among users to ensure the smooth functioning of all transactions. For example, it is only possible to add a new 'block' to the chain after a consensual agreement by all participants.

The technology naturally guards against the monopolization of power by any single users because the computational power limits how fast a machine can perform an operation. An elevated number of anonymous network participants compete to validate transactions through the computational power generated by their hardware called 'mining'Any attempt to improperly influence the validation process of the system becomes exponentially too costly to be viable. This assures that no single network user can take control of the blockchains (Nakamoto, 2008).[4]

The result is a decentralized public ledger that does not require a *Trusted Third Party* to validate transaction, as is currently practiced (i.e., by central banks and institutional regulators). The blockchain network keeps a complete record of all transactions it facilitated, employing "a distributed append-only timestamped data structure" (Casino et al., 2019). All transacting parties document their transaction within the decentralized public ledger and use the rest of network as witnesses to the transaction's authenticity.

[4] For example, doubling the computational power takes a substantial financial investment and is computationally impractical.

Blockchain is therefore effectively a technology that is ‘trustless’ (i.e., it does not require ‘trust’) as opposed to the traditional institutions that requires consumers to trust a third party (Luther and Smith, 2020).

2.1 The rapid application of blockchain technology

Though we focus on blockchain for FIS, its potential in other sectors is far reaching, both private and public, and will disrupt many traditional institutional settings (Casino et al., 2019). For example, it is already being used in the energy sector (EnerChain, 2017), healthcare (Deloitte, 2016) and aerospace (AIA, 2019; Wasim et al., 2021). Strong growth is forecasted in other sectors that are experimenting with it, for example, supply chain management and logistics (Saberi et al., 2019), market monitoring, education (Alammary et al., 2019), and the creative industries, copyright protection, intellectual property, and non-fungible tokens (NFT) (Heimbach et al., 2023). Overall, in 2022 the global market was estimated at US$3.4 billion, and projected to grow to US$19.9 billion in 2026 (CARG estimated 43%; GIA, 2022).

In financial intermediation, the first application of blockchain was, as mentioned, the cryptocurrency – an electronic payment system based on cryptographic proof (Nakamoto, 2008). Bitcoin, the most well-known, rose to the headlines thanks to its linkage with the darkweb and the shadow economy (Doguet, 2013; Bearman, 2015).

More recently, Bitcoin, and other cryptocurrencies (also known collectively as altcoins; Bonneau et al. 2015) have been adopted by various financial institutions for legitimate and legal purposes (Boulton, 2015; Caffyn, 2015), stock exchanges (Underwood, 2016), and other financial transactions (Gallippi, 2014). In August 2022, the Federal Reserve (FED) announced new guidelines for allowing access to crypto-banks (i.e., interchangeably called novel financial institutions or novel-banks) to its “master account” with a three-tiered system of risk (FED, 2022). This is an important step towards a change in FIS and would mean that novel-banks could operate independently, without requiring partnership nor intermediation from traditional-banks.

Bitcoins has long been synonymous with cryptocurrency and blockchain in general. For example, in 2016, 80% of the scientific papers continued to refer to Bitcoin when meaning cryptocurrency or blockchain (Yli-Huumo et al., 2016). By the end of 2021, the landscape changed dramatically and FIS now includes more than 16,000 cryptocurrencies[5], around 34,000 cryptocurrency ATMs worldwide, and more than 300 million cryptocurrency users (Yahoo Finance, 2021). Initially, the number of crypto exchanges were limited, with Mt. Gox being a virtual monopoly that dominated about 90% of BTC-USD trading.[6] Recently, this ballooned into around 451 blockchain assisted exchanges, segmented by geographic location and crypto-currencies traded.[7]

[5] Other digital currencies that use blockchain have been gaining importance, e.g., Etherum, Ada, Cardano, and Litecoin among many, some more widely used or better technically designed than others (Haferkorn and Diaz, 2014).
[6] Bitcon Price and Chart in US$
[7] Main crypto exchanges are Binance, a relatively new player from 2017, has become the market leader by capitalization.

The growth in this sector created more robust and trustable platforms (Tschorsch and Scheuermann, 2016; Cheah and Fry, 2015; Urquhart, 2016) but also added to the inherent trading risks and volatility, which have long being associated with cryptocurrencies as a whole (Glaser et al., 2014; Sapuric and Kokkinaki, 2014; Cheung et al., 2015).

2.2 The welfare benefits of adopting blockchain in FIS

Philippon (2015, 2012) quantitatively show that the development of information technology (IT), lead to breakthrough innovations, functionality, productivity, and drastically lowered the unit cost of most goods and services. However, Philippon shows that it did not lower the unit cost of FIS, which has been stable at around 2 percent for over century. Gennaioli et al. (2015) provides one explanation, i.e., investors' risk tolerance rises with more trust in FIS technology, which allows FIS firms to charge higher premiums. Because trust is a scare resource, improvements in IT do not necessarily translate into lower cost. Glode et al. (2012) argues that IT pushes firms to over-invest in financial expertise to protect themselves against risk and promote their services, which raises costs further.

The outcome is a traditional-banking institution that is oligopolistic and more costly (Dong et al., 2021). However, blockchain enabled crypto banking could restructure FIS as a perfectly competitive sector, lowering the cost to consumers and raising their welfare. Furthermore, Paladini et al. (2021) highlight that blockchain enabled FIS is being integrated more rapidly in countries where the population has less access to traditional banking (e.g., developing countries in Asia and Africa). For example, many women and low-income families do not even have access to traditional bank accounts and are severely borrowing constrained. Blockchain democratizes the system and empowers minority groups, and offers, even in developed countries, more opportunities for crowdfunding (Bogusz et al, 2020).

Blockchain enabled FIS would help to lower costs for consumers and business, including lower overseas remittances costs. This could secure access to players kept otherwise outside the traditional banking institutions, which is particularly important for emerging economies. For example, El Salvador recently adopted bitcoin as a national currency because of this point (The NYT, 2021).

Paladini et al. (2021) discuss other "social" activities which currently require traditional FIS, but that blockchain-enabled FIS could do better. For example, associating digital currencies with real assets (e.g., vehicles, land, intellectual property, and other legal activities), crowdfunding (whereby tokens are used as preorders of goods or as ownership shares), fundraising initiatives, and incorporated into Shariah-compliant institutional settings.

CoinmarketCap acquired Binance in April 2020. Other main crypto exchanges are Coinbase Exchange (traded in the US stock exchange and used in more than 100 countries), Gate.io, OKX (based in the Seychelles), LBank (Hong Kong) and Bitflyer (the most trusted in Japan).

The main attraction of blockchain is that it removes intermediary validated operations that create market power (Thakor, 2020; Frolov 2020; Paladini et al., 2021). Transactions become ‘trustless’ and can perform Peer-2-Peer (P2P) and smart contracts, which are predefined execution of agreements stored on blockchains that do not require intermediation. This technology is already disrupting traditional institutional setups. For example, they remove administration and other service costs, and improve business processes. Automation reduces the cost of capital and labor because expensive buildings for accommodating ‘human’ workers and customers are no longer necessary, and they remove costly deposit-gathering activies (Zhu et al., 2022; Ante, 2021; Gowda and Chakravorty, 2021; Boot et al., 2021; Vives, 2019; Buterin, 2014; Szabo, 1997). Furthermore, blockchain powered FIS is being outsourced to consumers themselves (similar to the demise of travel agencies for buying flight tickets), lowering operating costs even further. Finally, the fixed costs of developing computer-based platforms are much cheaper compared to the fixed costs required to setup traditional banking models. With crypto-banking, consumer pay less[8] and are indifferent, or better off, in terms of the time transaction costs.[9]

To combat the entry of new competition, traditional banks are using a two-pronged approach. First, they are lobbying governmental institutions against the direct access of crypto-banks to central bank deposits, citing the risks they pose and their unfair access, given that traditional-banking has much stricter rules.[10] This is, however, a weak argument. If crypto-banks do not provide loans and profit from interest rate spreads, and hold 100% reserves, they do not pose a maturity transformation risk as traditional-banking do. Consequently, the US FED recently announced new guidelines that provide a consistent risk-based set of parameters for reviewing requests to access the FEDs accounts and payment services. If, whenever, crypto-banks also provide loans, this would put them within a different risk tier that would need to be reconsidered (FED, 2022).

A growing number of economists support these changes. They also argue that crypto banking should focus on supplying retail payment media, driven by technological innovation. However, since central banks are not equipped to understand and integrate new technologies (Sehaput &Innet, 2023), they should therefore focus on supplying the wholesale settlement system, rather than fruitlessly trying to catch-up.

The second prong used by traditional banks is to acquire existing fintech platforms or develop their own blockchain-enabled (as implemented, for example, by JPMorgan, Citi, Wells Fargo, US Bancorp, PNC, Fifth

[8] Currently, in traditional-banking, wiring funds internationally from New York to London requires $25 wire transfer fee plus additional fees of up to 7%. Crypto banking is nearly costless.

[9] It could take up to 10 minutes to settle a Bitcoin transaction, and newer cryptocurrencies are even faster. Comparatively, transferring funds internationally through the SWIFT system could take up to three days, and 60 percent of B2B payments require manual intervention that require around 15 to 20 minutes per transaction (Gowda and Chakravorty, 2021).

[10] Read further at https://www.ledgerinsights.com/federal-reserve-master-account-crypto-stablecoins/

Third Bank, Signature Bank and Bank Hapoalim). In a survey among central banks, Boar and Wehrli (2021) find that 72 percent are conducting pilots and practical implementation of digital currently, focusing on both retail and wholesale (see also BOI, 2021; WEF, 2019). In 2019, the International Monetary Fund (IMF) and World Bank (WB) launched a private blockchain and quasi-cryptocurrency called "Learning Coin" (FT, 2019).

In conclusion, blockchain enabled FIS is being adopted rapidly, and likely to displace traditional banking because of its significant lower costs. However, as we will discuss in Section 4, there are three main barriers that hinder its adoption. But before outlining them, we develop a stylized model to demonstrate the welfare costs of these barriers.

3 A Stylized model of blockchain-enabled FIS

To make our point as simple as possible, we setup a stylized general equilibrium model to show that barriers that impede on the adoption of blockchain lower welfare ceteris paribus. In this model, we focus on the institutional changes in FIS, but could easily be extended to many other sectors.

The purpose of FIS institutions is to channel capital from households towards production. FIS has two segments i. Segment $1 \in i$ is the traditional banking institutions, which we setup as an oligopolistic segment. Segment $2 \in i$, is a blockchain-enabled open-access FIS, setup as a perfectly competitive segment. The evidence points to them being substitutes (e.g., Tang, 2019).

In this static model, the economy has a pre-defined level of available blockchain-enabled cryptocurrency $\bar{B}$ with unit price p_B. For example, these could be the number of bitcoins that have already been mind and available for FIS. Furthermore, there is a level of barriers $\gamma = (0,1)$ that creates frictions and raises the cost of this instrument in FIS. To simplify, we lump all barriers into one parameter, which we later explain (in Section 4) as being a combination of legal, technical, and environmental barriers.

Other related models have already integrated FIS within a general equilibrium (GE) setting, as we do here. For example, Kang and Lee (2022) develop a GE search-model with money and bitcoin as competing instruments of exchange. In their model, households cannot internalize the congestion they create in the confirmation of bitcoin transactions (calibrated to 10 minutes per confirmation). Therefore, welfare is lower in a FIS institutional setting with both money and bitcoin compared to a money-only FIS. In our model, congestion is determined exogenously by the available technology rather than endogenously. Schilling and Uhlig (2019a; 2019b) construct a GE model with a central bank-issued money and bitcoin and use the same model to study two issues: (i) cryptocurrency pricing and various conditions for speculation to occur in equilibrium, and (ii) the agent's indifference between purchasing goods with bitcoins or dollars depends on the size of the value-added tax and miners' transaction fees.

Lockwood and Yerushalmi (2019) developed a GE model where households can either use cash and/or a bank account with services (such as debit cards) for the purchase of different varieties of goods. They show that optimally, these payment services should be taxed differently. Dong et al. (2021) develop a GE model with an endogenous number of oligopolistic banks that channel credit to firms with a frictional search-and-matching component. In our model, we also setup traditional-FIS as an oligopoly with an endogenous number of monopolistic-competitive firms.

3.1 Household utility and aggregate production

Households are endowed with a fixed amount of real capital $\bar{k}$, which is channeled to aggregate production through FIS. The household maximizes a strictly increasing and concave utility function U

$$\underset{y}{\text{Max}} \quad U = y(k) \tag{1}$$

$$\text{s.t.} \quad y \leq r_D \bar{k} + p_B \bar{B} \tag{2}$$

whereby demand for the aggregate good is y which we normalize to $p = 1$. Expanding this model to include labor and multiple goods is simple, but unnecessary for making our point.

Households deposit capital in FIS for a unit return of r_D and FIS segments (traditional and blockchain) channel it to aggregate production for a unit return of r. To simplify the model, we assumed that the economy has a single aggregate competitive production sector $y = f(k)$ that is indifferent whether capital comes from traditional or blockchain FIS. Its demand for capital is $k = \sum_i k_i$. Production firms maximize their profit function

$$\underset{k}{\text{Max}} f(k) - rk \tag{3}$$

and as usual, the solution as a mixed complementarity format is

$$f_k - \text{r} \geq 0, y \geq 0, [f_k - r] \geq 0 \tag{4}$$

whereby production is $y > 0$ if firms make zero profits $f_k = r$. Otherwise, they would not produce $y = 0$ if profits are non-positive, $f_k > r$. Note that f_k refers to the partial derivative of function f to k, and recall that $p = 1$.

3.2 Traditional banking FIS

Traditional bank institutions are known to exhibit economies of scale in setting-up costs, administration, search costs, membership fees, etc. (Benston, 1965; Mullineaux, 1978; Wheelock and Wilson, 2012; Dong et al., 2021). We therefore use a monopolistic-competitive model with endogenous number of banks $n \in N$. Each bank enters or exits this segment freely, and in equilibrium makes zero economic profits.

Aggregate production y demands a total of k_1 capital from traditional FIS at a unit cost of r. Households deposit an amount D_1 of capital into traditional FIS at a unit cost r_D, which banks channel to firms at a unit cost of r with a markup (spread). Banks incur a fixed operating cost F_n with unit price p_{FC}, and in equilibrium, it will be a portion of excess profits that will cover its fixed costs in production.

The problem of the individual bank is to

$$\max_{D_{1n},F_n} \pi_{1n} = rk_{1n} - (r_D D_{1n} + p_{FC} F_n) \quad (5)$$

$$\text{s.t.} \quad k_{1n} \leq D_{1n} \quad (6)$$

where $D_1 = \sum_n D_{1n}$ is the total capital deposited in traditional FIS, and $k_1 = \sum_n k_{n1}$ is the total supply of capital reaching aggregate production from traditional FIS.

Omitting the subscript 1, for a moment, the revenue that an individual bank n receives by supplying capital is rk_n, where the return on capital r is a function of the supply of all available loans k. The marginal revenue for each individual bank is $MR_n = \left(r + k_n \frac{\partial r}{\partial k}\right)$ and assuming that $\frac{\partial k}{\partial k_n} = 1$, i.e., a one unit increase in a bank's own supply is a one-unit increase in the market supply. As usual, in the literature with some manipulation, we obtain $MR_n \approx r\left(1 - \frac{1}{N\eta}\right)$ where $\frac{1}{\eta} = -\frac{\partial r}{\partial k}\frac{k}{r}$ is defined as the inverse price elasticity of loans, and $\frac{k_n}{k} = \frac{1}{N}$ is the market share of bank n. Finally, in this symmetric case, each bank behaves as a constant return to scale monopoly that chooses production at point $\eta = 1$. Therefore, the monopolistic-competitive bank faces an overall demand that is N times more elastic.

Equating marginal revenue with marginal cost, and re-introducing subscript 1 to represents traditional FIS, the mixed complementarity zero profit condition is

$$r_D - r\left(1 - \frac{1}{N}\right) \geq 0, k_1 \geq 0, \left[r_D - r\left(1 - \frac{1}{N}\right)\right] k_1 \geq 0 \quad (7)$$

whereby (7) says that if a traditional FIS makes zero economic profit, banks will channel capital $k_1 > 0$. Otherwise, if profits are negative, they would shut down $k_1 = 0$, i.e., they will not transfer any capital. In equilibrium, the markup set by traditional banks is $\frac{r}{r_D} = \frac{N}{N-1}$.

We furthermore assume that a unit of the fixed operating cost is created by a unit of deposit. Its mixed complementarity equation is, therefore,

$$r_D - p_{FC} \geq 0, N \geq 0, [r_D - p_{FC}]N \geq 0 \quad (8)$$

(8) says that when $N > 0$, a portion of the economy's capital resources are diverted to cover the fixed operating costs, $r_D = p_{FC}$. Otherwise, if $r_D > p_{FC}$, banks would shut down, i.e., $N = 0$.

Plugging the left-hand-side of (7) into the zero profit condition for individual traditional banks, i.e., $rk_{1n} \geq r_D D_{1n} + p_{FC} F_n$, and given that $k_{1n} \leq D_{1n}$ and that $Nk_{1n} = k_1$, obtain the optimal number of banks

$$p_{FC} \geq 0, \sqrt{\frac{rk_1}{p_{FC}F_n}} - N \geq 0, p_{\mathrm{FC}}\left(\sqrt{\frac{rk_1}{p_{FC}F_n}} - N\right) \geq 0 \tag{9}$$

Again, (9) is a mixed complimentary equation that shows that a higher return on loans rk_1 raises the number of banks, but that higher value of fixed cost F_n lowers their numbers.

3.3 Blockchain-enabled FIS

We assume that the blockchain FIS is a perfectly competitive segment. Households deposit D_2 capital which it channels to aggregate production as k_2 . The profit function of the blockchain FIS is

$$\underset{D_2}{\mathrm{Max}}\, \pi_2 = rk_2 - (r_D D_2 + [p_B(1+\gamma)]\bar{B}) \tag{10}$$

$$\text{s.t. } k_2 \leq \min\{D_2, \bar{B}\} \tag{11}$$

where (11) assumes that blockchain technology (e.g., bitcoins) requires in fixed proportion of deposits and bitcoins to associated each other. Furthermore, the government imposes barriers $\gamma \geq 0$ that raise the cost of blockchain FIS. They create a dead-weight loss of $\gamma p_B \bar{B}$.

Finally, the market clearing condition for capital is $\bar{k} = \frac{y}{r}$ given that $r > 0$. The market clearing for blockchain technology is $\bar{B} = \frac{r}{p_B} D_2$, given that $p_B > 0$.

3.4 An illustrative example

As an illustration, we simulate this "stripped-down" model using the GAMS/MPSGE computer software.[11] We do not attempt to calibrate to real data because the main parameter γ is an unknown (i.e., a study of its own). Our main contribution is to conceptualize the problem, highlighting the need to formalize the regulatory framework.

Table 1: Parameters for the "stripped-down" model

Description	Parameter	Value
Total capital, $	$\bar{k}$	100
Total blockchain coins in circulation, #	$\bar{B}$	80
Individual traditional bank profit margin (markup) *		25%
Herfindhal-Hirscham Index (HHI)*		20%
Barriers to Blockchain	γ	0 to 8

* These parameters are calibrated for a case where $\gamma = 0$.

Table 1 provides the key parameter used. The supply of capital is set to $\bar{k} = 100\$$ and the number of

[11] www.gams.com. The code used is available upon request.

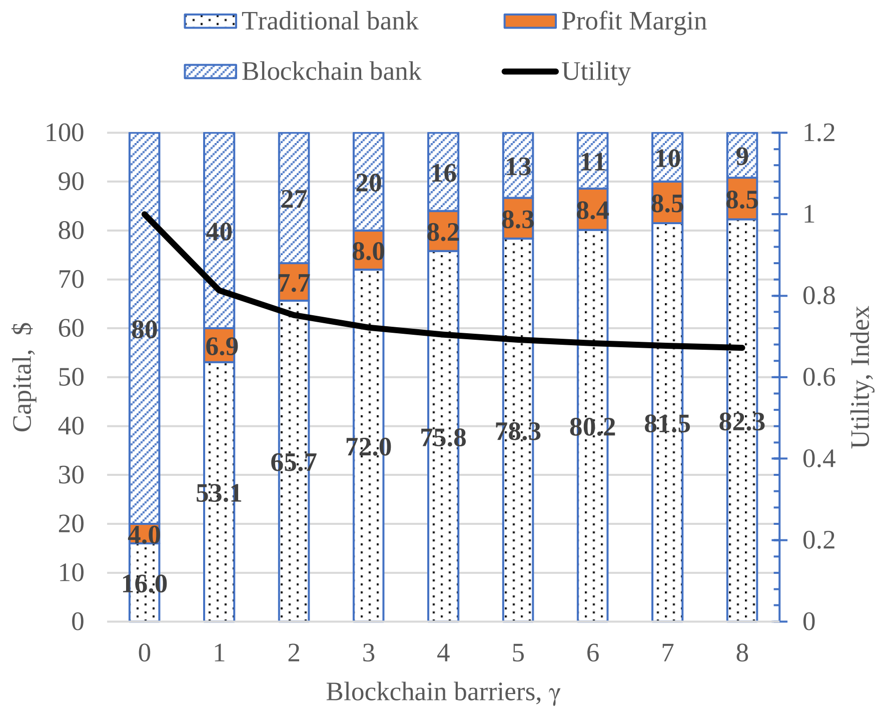
“mined” blockchain coins is $\bar{B} = 80$. For convenience, at $\gamma = 0$, we set the Herfindahl-Hirscham Index (HHI) to 20% - meaning the traditional FIS would be an oligopoly of five banks. We furthermore set the profit margin (markup) per bank to 25%.[12]

Figure 1 illustrates our result. First, the figure shows that the level of available capital in the economy is always fixed at $\bar{k} = 100\$$ for all simulations. However, as regulation γ falls (from right-to-left), an increasingly higher proportion of capital flows through blockchain FIS rather than traditional FIS. Second, household utility rises when these blockchain frictions are removed because when the number of traditional banks falls (see Figure 3), the total capital used to cover the operating costs falls. This means that less resources are duplicated and more of the capital is used for production rather than supporting the operation of traditional FIS. Figure 1 shows that the total capital diverted to profit margin falls from around 8$ to 4$ alongside a decrease in the number of banks from 11 to 5 in Figure 3.

One interesting aspect of this model is that traditional FIS institutions could be completely displaced (shut down) if more blockchain coins were available, i.e., by raising $\bar{B}$ or assuming an improvement in blockchain technology. Once traditional banking shuts down, utility cannot rise any further because all available capital is now already flowing through the new perfectly competitive banking system. A fully dynamic model could show, however, that having capital used more effectively, the economy could be projected to a higher growth path. But this is an unnecessary complication that adds little to our discussion.

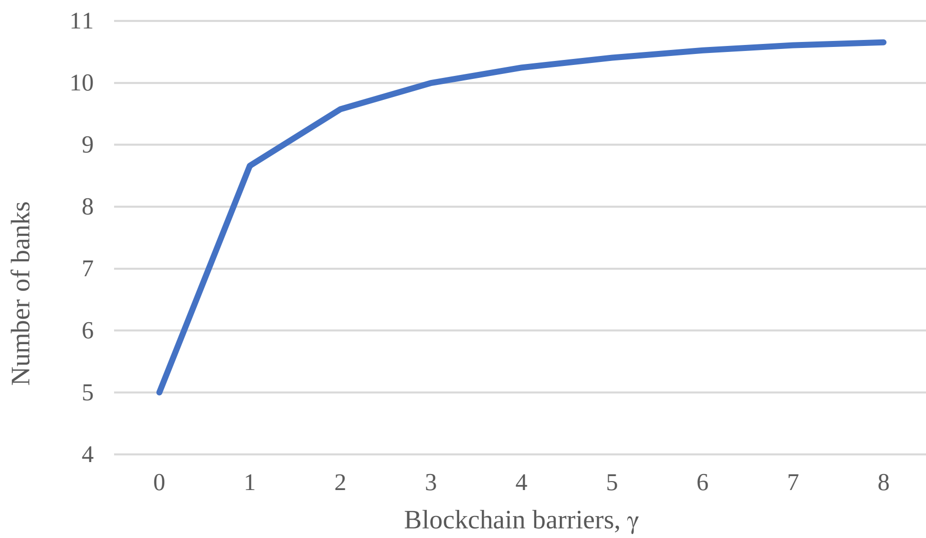
[12] As an example, Dong et al., (2021) estimates the HHI to 12% - meaning around 8 banks, and the profit margins at around 3.2%.

Figure 1: Volume of capital channel, $



The figure shows that with lower barriers to blockchain, more capital flows through blockchain-bank and less through traditional-banks, which also include profit margins.

Figure 2: Number of traditional banks falls with less barriers



The figure shows that lower barriers to blockchain leads to less traditional-banks.

4 What are the barriers for widespread adoption of blockchain?

The previous model demonstrated the potential welfare gains from adopting blockchain in FIS, once barriers are removed, but without specifying them. The purpose of this section is to provides a clear outline of the main barriers to blockchain.

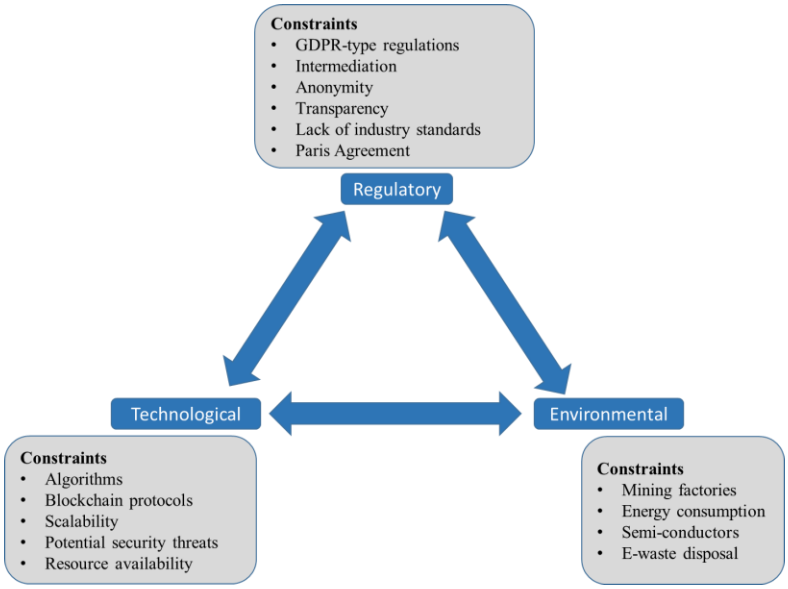
In its periodical survey on blockchain adoption, the consulting firm Deloitte (Deloitte, 2016) mapped the evolving perception of corporate users in terms of factors impeding blockchain adoption. Based on a survey of around 1500 senior executives, they conclude that technical-related issues and the overall institutional regulatory environment are the most relevant impediments. In addition, a less evident barrier but of equal importance are environmental concern.

We summarize, in Table 2, our collection of the main literature that discusses institutional and non-institutional barriers to blockchain technology, which we collate into three elements: Regulatory, Technological and Environmental. Figure 3 shows that all barriers are interconnected, and one cannot be addressed without the other, which we discuss further in Section 5.

Table 2: A summary of the blockchain barriers by academic sources

Institutional Barriers	References
Regulatory	
General framework	Mattila, 2016; Millard, 2018.
GDPR-related issues	Berberich & Stainer, 2016; Goddard, 2017; Finck, 2018; Eichler et al. 2018; Schwerin, 2018; Vives, 2019.
Intermediation	Voigt & Bussche, 2017; Haque et al. 2017; Sion et at. 2017; Frolov 2020.
Transparency	Iansiti &Lakhani, 2017; Tatar et al, 2020; Felten, 2012; Acar, 2018.
Immutability	Politou et al. 2017; Mantelero, 2013.
Non-Institutional Barriers	
Technological	
Efficiency	Swan, 2015; Crosby, 2016; Pieroni et al, 2018; Spurr & Ausloos, 2021.
Complexity	Xu et al., 2019; Li et al., 2017a; Taylor et al., 2020; Mougayar 2016, Saberi et al, 2019.
Scalability	Bhaskar & Chuen, 2015; Bowden et al. 2020; Zhang and Lee, 2020; Salimitari and Chatterjee, 2018, Conoscenti et al. 2016; Alphand et al. 2018.
Security-related threats	Li et al., 2020; Liang et al. 2018; Yli-Huumo et al. 2016; Vasek and Moore 2015
Resource availability	Bano et al. 2019; Leonardos et al, 2020.
Environmental	
Energy consumption	de Vries, 2018; Chohan, 2019; Giungato et al., 2017; Truby, 2018; Li et al., 2019; Foteinis, 2018; Calvo-Pardo et al., 2022; Baur & Oll, 2022; Bouraga, 2021; Cao et al., 2020; Bentov et al., 2014; Nandwani et al., 2019; Morabito, 2017; Mora et al. 2018.
Carbon footprint	Krause et Tolaymat, 2018; Stoll et al 2019.
E-waster	de Vries & Stoll, 2021; Fadeyi et al, 2019; Jana et al. 2020.

Figure 3: Three pillars that constrain blockchain



4.1 Institutional barriers: regulatory

The most critical barrier to a mainstream application of blockchain is the lack of a clear institutional regulatory framework. Without it, adopting the technology might do more harm than good, and in some cases, might legally be infeasible or against the law, as the recent scandals discussed above show. The aim of regulation is to protect the system and consumers, which is however difficult to formulate since regulators cannot foresee or understand the implication of the technology itself. They have been playing catchup from the start.

Within the current regulatory framework, the first source of friction is intermediation. As blockchain removes the need for Third-Party Verification, the creation of a virtual alternative market in which people can directly interact with one another means that new rules need to develop and upheld within the virtual world. Conflicts and irregularities in the virtual world will need to be resolved by real-world interventions (e.g., policing, legal disputes, etc.; E.g., the FTK case, which required the intervention of law enforcement agencies to apprehend and detain). Financial policies will have to adapt accordingly.

Paladini et al. (2021) reviews some of the existing regulator frameworks, providing evidence of how daunting any harmonization or even coherent application of the existing laws can be (see also Mattila, 2016; Millard, 2018). The recent scandals, previously mentioned, have only reinforced the regulators and central authorities' cautionary approach, especially in advanced economies that have complex regulatory framework and highly regulated financial sector (such as in the US, UK and other EU countries). Moreover, there are aspects in the EU's general regulations that present specific points of frictions with blockchain technology.

The General Data Protection Regulation (GDPR) of 2016, is probably the most important of them, especially in terms of implications (Finck, 2018; Eichler et al. 2018; Vives 2019), since it does not stop at the EU borders but applies every time an EU subject is involved (Article 3 of the GDPR). It seems somehow ironic that the EU, being the second biggest markets for blockchain applications (see Coinbase, 2022), is also the region where the most serious challenges have been raised.

There are three main aspects where GDPR clashes with blockchain technology. The first concerns decentralization and the role of intermediaries (or lack of them) (Frolov 2020). GDPR legally requires the existence of 'a data controller' (Article 4) for all online activities that can go under the (very comprehensive) remit of privacy law (Goddard, 2017). Such controller, be it a legal entity or physical person, has the function to 'protect' the rights of the subjects whose data belongs to in case those rights have been actioned (Voigt & Bussche, 2017; Haque et al. 2017; Sion et at. 2017). Strict rules regulate the identification and the prerogatives of data controller, together with the fines for infringements of those rights. As Article 22 of the GDPR states, '*the data subject shall have the right not to be subject to a decision based solely on automated processing, including profiling, which produces legal effects concerning him or her or similarly significantly affects him or her*'. It therefore directly conflicts with the main benefits and intrinsic value of blockchain, which make the presence of a central authority, of any kind, redundant.

The second covers the main interest of the GDPR, i.e., 'data protection by design' (Article 20, Article 25; Tatar et al, 2020) which contradicts with the inherent tamper-proofness and transparency of blockchain technology (Iansiti &Lakhani, 2017). This is another clear example of opposing design philosophies whereby blockchain uses distributed ledger verification, openly viewed by all, which directly contrasts with the confidentiality prescribed by the GDPR (Article 20).

The final point of conflict is blockchain's immutability and how it clashes with data protection in the GDPR. One of the most valuable and well-known characteristics of blockchain is the impossibility to alter past transactions and their systemic tracking and define its intrinsic value and removes the need for third-party verification of transactions. However, this characteristic directly clashes with two fundamental articles of the GDPR, namely, Article 16 that regulates the data subject's right to rectification, and Article 17 that states the right to erasure, i.e., the 'right to be forgotten', (Politou et al. 2017; Mantelero, 2013). In blockchain, any attempt to implement the right to be forgotten will require modifying data stored in blocks of the chain, therefore affecting its consistency and, eventually, its reliability, which will undermine its whole architecture.

There are additional clashing points, directly connected to Article 17 and concerning anonymization procedures (Felten, 2012; Acar, 2018), which however, may well represent part of the solution to settle privacy issues of the blockchain if properly addressed.

These legal hurdles are not only concerns within the EU. In the US, for example, where blockchain technologies are the most widespread, new laws protecting online consumer rights have been increasingly scrutinizing blockchain. The California Consumer Privacy Act (CCPA) legislation of June 2018 is in some respect, even more restrictive than GDPR (CCPA, 2018).

Besides GDPR and CCPA legislation, advanced economies have yet taken a firm stance in nominating an authority in charge of oversight. In the EU, there is no EU Commission agency exclusively in charge of decentralized technologies in general, blockchain included. The existing legal provisions about smart contracts and tokenization are still fragmentary and do not address the fundamental points of conflict (EU Blockchain Observatory and Forum, 2018).

The regulatory framework that could lead to the adoption of blockchain more widely is therefore still sketchy and varies greatly from country to another. Although, due to the 2022 scandals, this is probably an area where changes will happen quicker compared to, for example, ones addressing environmental constraints. Given the current climate, it is difficult to foresee how the new institutional framework will take shape, especially as they are directly linked with other considerations as we continue to discuss below.

4.2 Non-Institutional barriers: technological

Innovation is a core characteristic of blockchain, which requires sophisticated technology, and compliance with current institutional settings to allow for its integration. Two decades ago, when blockchain was in early development, compliance was less of an issue. Only a handful of countries/organizations used it so long as it was costly to adopt (e.g., by underdeveloped countries and organizations). Nowadays, substantial technological improvements, being open source, and cost reduction in the hardware and software, have made blockchain available worldwide. The subsequent exponential increase in usage raises its network effect value, which raises demand even further.

A basic entry level requirement must consider issues such as TPS (transaction per second) and other scalability issues (Bhaskar and Chuen, 2015; Bowden et al. 2020). Xu et al. (2019) summarize three generations of blockchain protocols: Blockchain 1.0 for digital currency, Blockchain 2.0 for digital finance, and Blockchain 3.0 for IoT (internet of Things). The last two include applications such as smart contracts and Peer-2-Peer, which intrinsically are efficient, self-regulating protocols, with automated and extended validation capabilities (Swan, 2015; Crosby, 2016; Pieroni et al, 2018). These items are essential elements for wide scale applications for blockchain-enabled FIS.

When designing a blockchain-enabled Fintech platform, a few defining factors must be considered. First, efficiency directly relates to the verification process required to confirm and write transactions. The type of protocol implemented will dramatically affect efficiency and, simultaneously, its resource consumption. For example, one Bitcoin transaction takes about 10 minutes to be confirmed (i.e., the time required for a single block to be verified and added to the blockchain). ‘Lighter’, more modern protocols are quicker and require less energy consumption (e.g., Litecoin processes a blockchain in 2.5 minutes; Spurr and Ausloos, 2021).

The second is complexity, which also represents an important area of criticality. Highly efficient protocols become more sophisticated, but at the same time more complex and possibly more vulnerable (Li et al., 2017; Taylor et al., 2020). They have therefore mainly been adopted in high-return instruments such as digital currencies and NFT (non-fungible tokens), and not adopted in a wider range of uses (Mougayar 2016, Saberi et al, 2019).

Third, scalability, i.e., how quickly can blockchain size-up to meet the growing demand for the network itself, is an issue mainly determined by the protocol selection (Zhang and Lee, 2020; Salimitari and Chatterjee, 2018). All networks must consider the trade-off between the benefits and costs, namely: speed, centralization, and security. For example, designing a quicker network might require sacrificing security and/or decentralization. Alternatively, achieving higher security might require sacrificing openness and/or speed.

In the case of blockchain, there is often an inconsistency in the use of technical protocols adopted for validation among the different applications, and this issue is progressively growing worse with the expansion of the IoT (Conoscenti et al. 2016; Alphand et al. 2018). Even at a narrower level such as fintech application, there is a proliferation of different protocols that 'hampers managers and investors from making business decisions and comparing and understanding newly proposed protocols,' (Leonardos et al, 2020). Considering that blockchain protocols provide a similar function to bank institutional authorities, the choice of which protocol to adopt has a major impact on the performance of the system, its security, and the trust the system itself elicits from its users. The choice of the protocol is, therefore, a crucial component of the adoption of the blockchain technology. Furthermore, as demand for blockchain rises, the interlinkage between efficiency and scalability raises congestion (i.e., the time it takes to verify a transaction). The model of Kang and Lee (2022), which focuses on this issue, shows therefore that money-only provides higher welfare than a system with bitcoin and money. In our stylized model in Section 3, we assumed the supply of blockchain technology is fixed (e.g., in the number bitcoins 'mind') and hence a superior technology is preferable. However, we could have extended with an additional feature that endogenizes supply (from being fixed, to upward sloping and even backward-bending) to produce a range of results – including Kang and Lee's.

Fourth, potential security threats related to blockchain applications is an issue commonly flagged in many corporate surveys and extensively analyzed in blockchain technical literature (Li et al., 2020; Liang et al. 2018). Even before the technology itself gained popularity, security threats have been discussed frequently because of its conflation with cryptocurrency and the Dark Web (Yli-Huumo et al. 2016; Vasek and Moore 2015) and the anonymity of the transactions, which give it, unjustifiably, a shady reputation even today.

Last but not the least, resource availability. The implementation of blockchain solutions depends on the equipment used for operating it, i.e., computational power, and the energy consumption required that have a direct impact on the protocol stability and its efficiency (Bano et al. 2019; Leonardos et al, 2020). Which leads to consider the final set of barriers: the environmental factors.

4.3 Non-institutional barriers: environmental

Blockchain is notoriously electricity-hungry (de Vries, 2018; Chohan, 2019; Giungato et al., 2017; Truby, 2018; Li et al., 2019) especially when producing ('mining') the digital currencies and tokens. Governments and environmental regulators are closely watching the growth in blockchain and its effect on climate change and carbon footprint. Therefore, environmental barriers have been increasingly introduced alongside criticism on the technology itself. While all studies agree that the energy requirements for the blockchain protocols are significantly high, the full cost is unknown because of the many different coins available. Each has a different algorithm and consensus protocols (i.e., validation mechanisms) with a different ecological footprint.

Bitcoin is the most energy-hungry of all coins (Foteinis, 2018; Calvo-Pardo et al., 2022; Baur & Oll, 2022). In July 2018, it was estimated that its energy consumption was 70 TWh (terawatt / hours per year), around Austria's consumption in 2014, or roughly 0.35% of total worldwide energy consumption (WEF 2019). Other estimates are more conservative, e.g., Stoll et al (2019) estimate it at 45.8 TWh, which is still worryingly high. Aggregating four additional cryptocurrencies, the energy consumption rises marginally by at least 30TWh higher (Swanson, 2018).

In terms of its carbon footprint, estimates are also unclear and vary widely. Some estimate that Bitcoin produces 3 to 15 MtCO2 (million metric tons of CO2; Krause et Tolaymat, 2018), others quantify 22 to 23 MtCO2 (Stoll et al., 2019) and up to as high as 63 MtCO2. Even taking an average value (e.g., mid 20s) is extremely high – equivalent to the emissions in Jordan or Sri Lanka.

Another environmental concern is the growing problem of e-waste, i.e., hazardous waste that comes from electronic equipment that are related to cryptocurrency mining. The increase of competition among mining factories forces operators to continuously upgrade their hardware (both ASIC miners and GPUs) and discarding the old equipment. According to estimates, bitcoin's yearly e-waste generation was about 30.7 metric kilotons in 2021, a level comparable to IT waste produced by the Netherlands (de Vries & Stoll, 2021). Per individual bitcoin transaction, this amounts to around 272 g of e-waste, which is an astounding value rate under any standard, which cannot be easily dismissed (Fadeyi et al, 2019; Jana et al. 2020).

What are the possible solutions to this problem? Technological changes in the consensus protocols, i.e., the algorithm that ensures all the peers agree on the digital ledger, could become more sustainable in the years to come (Bouraga, 2021). Currently, the most used protocol is the Prof of Work (PoW) which was adopted in 2009 to mine bitcoins. It is particularly energy intensive and environmentally costly compared to other payment methods. For example, credit card transactions are estimated at only 0.01 kWh of power, compared to bitcoin's 200 kWh (Mora et al. 2018).

There are, however, better environmentally friendly alternatives and many already operate. These use less energy-intensive algorithms, for example, Proof of Stake (PoS) – appearing in 2015 – is 12 to 14 times more energy efficient compared to PoW. Recently, newer protocols have been created and tested, such as Proof of Importance (PoI), Proof of Authority (PoA), and Proof of History (PoH) networks (Cao et al., 2020; Bentov et al., 2014; Nandwani et al., 2019; Morabito, 2017). Extensive surveys have been carried to evaluate the strengths and weaknesses of the competing protocols for future applications, taking energy consumption as one of the variables to be considered among the criteria of preferential adoption (Nguyen and Kim, 2018; Wang et al., 2019; Zhang and Lee, 2020).

5 Discussion: addressing the barriers with a combined approach

These institutional and non-institutional barriers discussed previously are all interconnected and often overlap (depicted in Figure 3), and it is therefore not possible to tackle each element separately. The lack of a suitable framework has driven many bitcoin mining facilities outside the EU, alongside cheaper energy in those regions (Li et al, 2019). China is another example of a country who had banned bitcoins and altcoins in mid-2021 because of its mistrust in this technology and its wider implication (Olcott and Szalay, 2021).

A solution to deal with the three barriers simultaneously is to focus on technology solutions that would address the regulatory institutional framework and promote more environmental-friendly mining technologies. For example, finding technology solutions that would reconcile with GDPR on two crucial issues, automated intermediation and immutability, would remove many regulatory and environmental barriers. We believe these items are likely to be addressed first and would encourage a better understanding of blockchain itself. In other words, a more GDPR friendly algorithm would go a long way to address the concerns posed by regulatory authorities.

With current algorithms (i.e., mainly PoW, the base behind bitcoins), the likely conflicts and irregularities in the virtual world will need to be resolved by real-world interventions, e.g., by policing, resolving legal disputes, etc. And although PoW is inefficient, we expect this area to develop more regulation and scrutiny, and especially as a response to the 2022/3 scandals. With newer algorithms, such as PoS, regulators will probably use a lighter touch because many of its technical characteristics will already be coordinated with policy.

But even if we continue with the current PoW blockchain, there is further scope for lowering barriers. Ongoing attempts at anonymization procedures, like hashing, that transform data beyond recognition and enable data controllers to treat personal data separately from other blocks (Felten, 2012; Acar 2018) would comply with GDPR requirements and enable "*rectification and erasure of personal data stored off-chain in* *appropriate databases in light with Articles 16 and 17 GDPR*" (The EU Parliament, 2019). Furthermore, new ways to configure distributed ledgers with noise to the data would lower barriers (Berberich & Stainer, 2016; Finck, 2018).

There are a few inventive technologies being developed that might come up soon. One is a two-party smart contracts that share information with the authorities in the event of a dispute (Benedetti, 2021). Another radical solution that would tick all the boxes of the threefold barriers to blockchain would be the massive adoption of a less energy-hungry, more configurable, and scalable algorithm used by Blockchain 3.0/IoT and integrated by open Fintech FIS models. The growing debate about the advantages of using Ethereum (ETH) algorithm as a baseline for IoT solutions, from NFTs to smart contracts and mobile-based applications, and even banking-related mechanisms (i.e., the Royal Bank of Scotland Clearing and Settlement Mechanism) is a good example. Considering that Ethereum is currently switching its computational algorithms from PoW to ETH2 PoS (Ethereum, 2023; Vukolić, 2016), its suitability as a highly scalable, more-environmentally friendly blockchain solution is rapidly growing. Moreover, ETH2, the new PoS-informed Ethereum, is designed with security in mind – requiring an extremely high number of 'block-validators' (instead of bitcoin 'block' miners) and, therefore a much more decentralized architecture–which will address potential security risks mentioned above.

Solutions will continue to be implemented with an eye on potential clashes with the GDPR articles. Clashes could be avoided by consistently identifying solution that ensure ownership of PII (Personal Identifying Information; Schwerin, 2018) to the users and putting in place consultation mechanisms with the regulatory authorities before releasing broad spectrum applications.

6 Conclusions

The blockchain revolution will go on, and the occasional setbacks cannot change this fact. On the contrary, the 2022/3 cryptocurrency scandals brought the issue into the limelight and accelerated the need for a long overdue updated of the regulatory framework at various institutional levels. The precise direction is yet unclear, and the bulk of blockchain applications will continue to focus on cryptocurrencies. But new and more sophisticated solutions are emerging that can make the technology truly global and cross-sectorial.

In this paper, we focused on blockchain-enabled FIS and its barriers for adoption (i.e., regulatory, technological, and environmental). But there are many other sectors likely to gain from blockchain such as healthcare, logistics, education and more. Emerging economies could particularly benefit because blockchain is an enabler for social innovation (Chen & Bellavitis, 2020; Dees & Battle Anderson, 2006; Nicholls, 2010;).

Swan (2015:7) went as far as defining blockchain as a "*fundamental for forwarding progress in society* *as Magna Charta or the Rosetta Stone*". Atzori (2017) believes that "*blockchain technology potentially allows individuals and communities to redesign their interactions in politics, business and society at large, with an unprecedented process of disintermediation on large scale, based on automated and trustless transactions*".

ETH2 will probably address most of the barriers highlighted in this paper, regulatory as much as the others, environmental first. The long process of transitioning from PoW to PoS algorithm (started in 2020) is expected to make its mark by 2024, according to some estimates. It is expected that some changes will partially accommodate GDPR-related regulatory concerns, and likely head the economy closer to the type of blockchain-enabled FIS and beyond that we envisioned.

7 References

AIA, 2019. Blockchain in Aerospace and Defense. Aerospace Industries Association (AIA). [Accessed: 27/04/2023].

Acar, G., 2018. Four cents to deanonymize: Companies reverse hashed email addresses. Freedom to Tinker, Princeton Center for Information Technology Policy. [Accessed: 27/04/2023].

Alammary, A., S. Alhazmi, M. Almasri, and S. Gillani, 2019. Blockchain-Based Applications in Education: A Systematic Review. *Applied Sciences* **9**(12), 2400.

Alphand, O., Amoretti, M., Claeys, T., Dall'Asta, S., Duda, A., Ferrari, G., Rousseau, F., Tourancheau, B., Veltri, L. and Zanichelli, F., 2018, April. IoTChain: A blockchain security architecture for the Internet of Things. In *2018 IEEE wireless communications and networking conference (WCNC)* (pp. 1-6). IEEE.

Ante, L., 2021. Smart contracts on the blockchain – A bibliometric analysis and review. *Telematics and Informatics* **57**, 101519.

Atzori, M. 2017. Blockchain Technology and Decentralized Governance: Is the State Still Necessary? *Journal of Governance and Regulation* 16, 1.

Bano, S., A. Sonnino, M. Al-Bassam, S. Azouvi, P. McCorry, S. Meiklejohn, and G. Danezis: 2019. SoK: Consensus in the age of blockchains. In: *Proceedings of the 1st ACM Conference on Advances in Financial Technologies*. pp. 183–198.

Baur, D.G. and Oll, J., 2022. Bitcoin investments and climate change: a financial and carbon intensity perspective. *Finance Research Letters*, *47*, p.102575.

Bearman, J.: 2015. The Rise and Fall of Silk Road: Part I. [Accessed: 27/04/2023].

Benston, G. J., 1965. Branch Banking and Economies of Scale. *The Journal of Finance* **20**(2), 312–331.

Benedetti, H., 2021. Public Blockchains and Applications. In *The Emerald Handbook of Blockchain for Business*. Emerald Publishing Limited.

Bentov, I., C. Lee, A. Mizrahi, and M. Rosenfeld, 2014. Proof of activity: Extending bitcoin's proof of work via proof of stake. *ACM SIGMETRICS Performance Evaluation Review* **42**(3), 34–37.

Berberich, M.; Steiner, M. 2016. Blockchain technology and the GDPR -- How to Reconcile Privacy and Distributed Ledgers? European Data Protection Law Review, 2 422-425

Bhaskar, N.D. and Chuen, D.L.K., 2015. Bitcoin mining technology. In *Handbook of digital currency* (pp. 45-65). Academic Press.

Boar, C. and A. Wehrli, 2021. Ready, steady, go? - Results of the third BIS survey on central bank digital currency. BIS Paper 114, Bank for International Settlements (BIS).

Bogusz, C., C. Laurell and C. Sandström, 2020. Tracking the Digital Evolution of Entrepreneurial Finance: The Interplay Between Crowdfunding, Blockchain Technologies, Cryptocurrencies, and Initial Coin Offerings. In *IEEE Transactions on Engineering Management* 67(4), pp. 1099-1108.

Bonneau, J. A. Miller, J. Clark, A. Narayanan, J. A. Kroll and E. W. Felten, 2015. SoK: Research Perspectives and Challenges for Bitcoin and Cryptocurrencies. *2015 IEEE Symposium on Security and Privacy*, pp. 104-121.

BOI, 2021. A Bank of Israel Digital Shekel: Potential Benefits, Draft Model and Issues to Examine. Steering committee report, Bank of Israel. [Accessed: 27/04/2023].

Boot, A., Hoffmann, P., Laeven, L., Ratnovski, L., 2021. Fintech: what's old, what's new? Journal of Financial Stability 53, 100836. https://doi.org/10.1016/j.jfs.2020.100836

Boulton, C., 2015. BNY Mellon Explores Bitcoins Potential. The Wall Street Journal. [Access: 27/04/2023]

Bouraga, S., 2021. A taxonomy of blockchain consensus protocols: A survey and classification framework. *Expert Systems with Applications*, *168*, p.114384.

Bowden, R., Keeler, H.P., Krzesinski, A.E., Taylor, P.G., 2020. Modeling and analysis of block arrival times in the Bitcoin blockchain. Stochastic Models 36, 602–637.

Buterin, V., 2014. A next generation smart contract and decentralized application platform. Ethereum White Paper. [Accessed: 27/04/2023].

CCPA, 2018. Title 1.81.5. California Consumer Privacy Act of 2018, [California Civil Code §§ 1798.100–1798.199]. [Accessed: 27/04/2023].

Chen, Y.; Bellavitis, C. 2020. Blockchain disruption and decentralized finance: The rise of decentralized business models. *Journal of Business Venturing Insights*, 13.

Caffyn, G.: 2015. Barclays Trials Bitcoin Tech With Pilot Program. CoinDesk. [Accessed: 27/04/2023].

Calvo-Pardo, H.F., Mancini, T. and Olmo, J., 2022. Machine learning the carbon footprint of bitcoin mining. *Journal of Risk and Financial Management*, *15*(2), p.71.

Cao, B., Z. Zhang, D. Feng, S. Zhang, L. Zhang, M. Peng, and Y. Li: 2020, 'Performance analysis and comparison of PoW, PoS and DAG based blockchains'. *Digital Communications and Networks* **6**(4), 480–485.

Casino, F., T. K. Dasaklis, and C. Patsakis: 2019. A systematic literature review of blockchain-based applications: current status, classification and open issues. *Telematics and Informatics* **36**, 55–81.

Cheah, E.-T. and J. Fry, 2015. Speculative bubbles in Bitcoin markets? An empirical investigation into the fundamental value of Bitcoin. *Economics Letters* 130, 32–36.

Cheung, A., E. Roca, and J.-J. Su, 2015. Crypto-currency bubbles: an application of the Phillips–Shi–Yu (2013) methodology on Mt. Gox bitcoin prices. *Applied Economics* 47(23), 2348–2358.

Chohan, U. W., 2019. Blockchain and Environmental Sustainability: Case of IBM's Blockchain Water Management. *Notes on the 21st Century (CBRI)*. Available at SSRN 3334154.

Christidis, K. and M. Devetsikiotis, 2016. Blockchains and smart contracts for the internet of things. *Ieee Access* **4**, 2292–2303.

CNN Business. 2021. Bitcoin's market value tops $1 trillion. (n.d.). Updated 19 February, 2021. [Accessed: 27/04/2023].

Conoscenti, M., Vetro, A. and De Martin, J.C., 2016, November. Blockchain for the Internet of Things: A systematic literature review. In *2016 IEEE/ACS 13th International Conference of Computer Systems and Applications (AICCSA)*. [Accessed: 27/04/2023].

Crosby, M., P. Pattanayak, S. Verma, V. Kalyanaraman, et al.: 2016. Blockchain technology: Beyond bitcoin. *Applied Innovation Review* 2(6-19).

Dees, J. G.; Battle Anderson, B., 2006. Rhetoric, reality, and research: building a solid foundation for the practice of social entrepreneurship, pp 144-168 in A Social entrepreneurship: new models of sustainable social change. Oxford University Press.

Deloitte, 2016. Blockchain: Opportunities for health care. Deloitte. [Accessed: 27/04/2023].

de Vries, A., 2018. Bitcoin's growing energy problem. *Joule* **2**(5), 801–805.

de Vries, A. and Stoll, C., 2021. Bitcoin's growing e-waste problem. *Resources, Conservation and Recycling*, *175*, p.105901.

Doguet, J. J.: 2013, 'The Nature of the Form: Legal and Regulatory issues surrounding the Bitcoin digital currency system'. *Louisiana Law Review* 73(4), 9.

Dong, M., Huangfu, S., Sun, H., Zhou, C., 2021. A macroeconomic theory of banking oligopoly. European Economic Review 138, 103864.

Eichler, N., Jongerius, S., McMullen, G., Naegele, O., Steininger, L., and Wagner, K., 2018. Blockchain, data protection, and the GDPR Blockchain. Bundesverband E.V., Tech. Rep.

Economist, 2015. Who is Satoshi Nakatomo? The Economist. [Accessed: 27/04/2023].

EnerChain, 2017. Gridchain: blockchain-based process integration for the smart grids of the future. [Accessed: 27/04/2023].

EU Blockchain Observatory and Forum, 2018. European Commission launches the EU Blockchain Observatory and Forum: Shaping Europe's digital future, Press Release 1-2-2018. [Accessed: 27/04/2023].

Ethereum. 2023. Home site. Proof of Stake (POS). [Accessed: 27/04/2023].

Fadeyi, O., Krejcar, O., Maresova, P., Kuca, K., Brida, P. and Selamat, A., 2019. Opinions on sustainability of smart cities in the context of energy challenges posed by cryptocurrency mining. *Sustainability*, *12*(1), p.169.

FED, 2022. Guidelines for Evaluating Account and Services Requests. Federal Research system, Board of Governors, [Accessed: 27/04/2023].

Felten, E., 2012. Does hashing make data ``anonymous"? Federal Trade Commission. [Accessed: 27/04/2023].

Finck M., 2018. *Blockchain Regulation and Governance in Europe*. Cambridge: Cambridge University Press.

Frolov, D., 2021. Blockchain and institutional complexity: an extended institutional approach. Journal of Institutional Economics 17, 21–36.

Foteinis, S., 2018. Bitcoin's alarming carbon footprint. *Nature*, *554*(7690), pp.169-170.

FT, 2019. IMF and World Bank explore crypto merits with blockchain project. Financial Times. [Accessed: 27/04/2023].

Gallippi, T. 2014. ESPN and BitPay Enter 3-Year Deal To Produce NCAA Bowl Game. Bitpay, Blog. [Accessed: 27/04/2023].

Gennaioli, N., A. Shleifer, and R. Vishny, 2015. Money Doctors. *The Journal of Finance* **70**(1), 91–114.

GIA, 2023. Global Blockchain Technology Market to Reach $19.9 Billion by 2026. Global Industry Analysts, Inc. CISION PR Newswire. [Accessed: 27/04/2023].

Giungato, P., R. Rana, A. Tarabella, and C. Tricase: 2017, ‘Current trends in sustainability of bitcoins and related blockchain technology’. *Sustainability* **9**(12), 2214.

Glaser, F., K. Zimmermann, M. Haferkorn, M. C. Weber, and M. Siering, 2014. Bitcoin - Asset or Currency? Revealing Users’ Hidden Intentions. *ECIS 2014 (Tel Aviv)*. Available at SSRN.

Glode, V., R. C. Green, and R. Lowery, 2012. Financial Expertise as an Arms Race. *The Journal of Finance* **67**(5), 1723–1759.

Goddard, M., 2017. The EU General Data Protection Regulation (GDPR): European regulation that has a global impact. *International Journal of Market Research* 59(6) 703-705.

Gowda, N., Chakravorty, C., 2021. Comparative study on cryptocurrency transaction and banking transaction. Global Transitions Proceedings, International Conference on Computing System and its Applications (ICCSA- 2021) 2, 530–534.

Haque, A., A. K. M. N. Islam, S. Hyrynsalmi, B. Naqvi and K. Smolander, 2021. GDPR Compliant

Blockchains–A Systematic Literature Review. In *IEEE Access*, 9, pp. 50593-50606, 2021

Heimbach, L., Kneip, Q., Vonlanthen, Y., & Wattenhofer, R., 2023. DeFi and NFTs Hinder Blockchain Scalability. ArXiv, abs/2302.06708.

Haferkorn, M. and J. M. Q. Diaz, 2014. Seasonality and interconnectivity within cryptocurrencies-an analysis on the basis of bitcoin, litecoin and namecoin. In: *International Workshop on Enterprise Applications and Services in the Finance Industry*. pp. 106–120.

Housley, R., 2004. Public key infrastructure (PKI). *The internet encyclopedia*.

Iansiti, M. and Lakhani, K.R., 2017. The truth about Blockchain", Harvard Business Review, 95(1), 118-127.

Jana, R.K., Ghosh, I. and Wallin, M.W., 2022. Taming energy and electronic waste generation in bitcoin mining: Insights from Facebook prophet and deep neural network. *Technological Forecasting and Social Change*, 178, p.121584.

Kang, K.-Y., Lee, S., 2022. Money, Bitcoin, and Monetary Policy. Journal of Money, Credit and Banking n/a.

Krause, M.J. and Tolaymat, T., 2018. Quantification of energy and carbon costs for mining cryptocurrencies. *Nature Sustainability*, 1(11), pp.711-718.

Leonardos, S., Reijsbergen, D., Piliouras G. 2020. Presto: A systematic framework for blockchain consensus protocols, *IEEE Transactions on Engineering Management*, 67(4), 1028-1044.

Lemieux, P., 2013. Who is Satoshi Nakamoto? *Regulation* 36(3), 14–16.

Li, X., Jiang, P., Chen, T., Luo, X. and Wen, Q., 2020. A survey on the security of blockchain systems. *Future generation computer systems*, *107*, pp.841-853.

Li, J., N. Li, J. Peng, H. Cui, and Z. Wu: 2019. Energy consumption of cryptocurrency mining: A study of electricity consumption in mining cryptocurrencies. *Energy* 168, 160–168.

Li, S., Liu, M. and Wei, S., 2017. A distributed authentication protocol using identity-based encryption and blockchain for LEO network. In *Security, Privacy, and Anonymity in Computation, Communication, and Storage* (pp. 446-460). Springer International Publishing.

Liang, G., Weller, S.R., Luo, F., Zhao, J. and Dong, Z.Y., 2018. Distributed blockchain-based data protection framework for modern power systems against cyber attacks. *IEEE Transactions on Smart Grid*, *10*(3), pp.3162-3173.

Lockwood, B., Yerushalmi, E., 2019. How should payment services be taxed? Social Choice & Welfare 53, 21-47.

Luther, W.J., Smith, S.S., 2020. Is Bitcoin a decentralized payment mechanism? Journal of Institutional Economics 16, 433–444.

Mantelero, A., 2013. The EU Proposal for a General Data Protection Regulation and the roots of the right to be forgotten. *Computer Law & Security Review*, 29, 3, 229–235

Mattila, J., 2016. The blockchain phenomenon–the disruptive potential of distributed consensus architectures.

Technical report, ETLA working papers 38.

Meng, W., E. W. Tischhauser, Q. Wang, Y. Wang, and J. Han, 2018. When intrusion detection meets blockchain technology: a review. *Ieee Access* **6**, 10179–10188.

Millard, C., 2018. Blockchain and law: Incompatible codes? *Computer Law & Security Review* **34**(4), 843–846.

Milmo, D., 2023. Crypto bank Silvergate announces liquidation amid sector turmoil. The Guardian. [Accessed: 27/04/2023].

Mora, C., Rollins, R.L., Taladay, K., Kantar, M.B., Chock, M.K., Shimada, M. and Franklin, E.C., 2018. Bitcoin emissions alone could push global warming above 2 C. *Nature Climate Change*, *8*(11), 931-933.

Morabito, V., 2017. Business innovation through blockchain. *Cham: Springer International Publishing.*

Mougayar, W., 2016. *The business blockchain: promise, practice, and application of the next Internet technology*. John Wiley & Sons.

Mullineaux, D. J., 1978. Economies of Scale and Organizational Efficiency in Banking: A Profit- Function Approach. *The Journal of Finance* 33(1), 259–280.

Nakamoto, S., 2008. Bitcoin: A Peer-to-Peer Electronic Cash System. [Accessed: 27/04/2023].

Nandwani, A., M. Gupta, and N. Thakur, 2019. Proof-of-participation: Implementation of proof-of- stake through proof-of-work. In: *International Conference on Innovative Computing and Communications*. pp. 17–24.

Nguyen, G., Kim, K. 2018. A survey about consensus algorithms used in blockchain, Journal of Information processing systems, 14, 1, 101-128.

Nicholls, A., 2010. The Institutionalization of Social Investment: The Interplay of Investment Logics and Investor Rationalities. Journal of Social Entrepreneurship 1, 70–100.

Olcott, E. and E. Szalay, 2021. China expands crackdown by declaring all crypto activities 'illegal''. *Financial Times*.

Pagnotta, E. and T. Philippon: 2011, 'Competing on Speed'. Technical Report w17652, National Bureau of Economic Research.

Paladini, S., E. Yerushalmi, and I. Castellucci: 2021, 'Public Governance of the Blockchain Revolution and Its Implications for Social Finance: A Comparative Analysis'. In: T. Walker, J. McGaughey, S. Goubran, and N. Wagdy (eds.): *Innovations in Social Finance: Transitioning Beyond Economic Value*. Cham: Springer International Publishing, pp. 293–318.

Philippon, T., 2012. Finance versus Wal-Mart: Why are Financial Services so Expensive? In: A. S. Blinder, A. W. Lo, and R. M. Solow (eds.): *Rethinking the Financial Crisis*. Russell Sage Foundation.

Philippon, T., 2015. Has the US Finance Industry Become Less Efficient? On the Theory and Measurement of Financial Intermediation. *American Economic Review* **105**(4), 1408–1438.

Pieroni, A., Scarpato, N., Di Nunzio, L., Fallucchi, F. and Raso, M., 2018. Smarter city: smart energy grid based on blockchain technology. *International Journal on Advanced Science Engineering Information Technology*, 8(1), pp.298-306.

Politou, E., Michota, A., Alepis, E., Pocs, M., Patsakis, C., 2018. Backups and the right to be forgotten in the GDPR: An uneasy relationship, *Computer Law & Security Review*, 34 6 1247--1257

Salimitari, M. and Chatterjee, M., 2018. A survey on consensus protocols in blockchain for IoT networks. *arXiv preprint arXiv:1809.05613*.

Saberi, S., M. Kouhizadeh, J. Sarkis, and L. Shen, 2019. Blockchain technology and its relationships to sustainable supply chain management. *International Journal of Production Research* **57**(7), 2117–2135.

Sapuric, S. and A. Kokkinaki, 2014. Bitcoin is volatile! Isn't that right? In: *International Conference on Business Information Systems*. pp. 255–265.

Schilling, L., Uhlig, H., 2019a. Some simple bitcoin economics. *Journal of Monetary Economics* 106, 16–26.

Schilling, L., Uhlig, H., 2019b. Currency Substitution under Transaction Costs. *AEA Papers & Proceedings* 109, 83–87

Schwerin, S., 2018. Blockchain and privacy protection in the case of the european general data protection regulation (GDPR): a delphi study. *The Journal of the British Blockchain Association*, *1*(1).

Sion, L., P. Dewitte, D. Van Landuyt, K. Wuyts, I. Emanuilov, P. Valcke, et al., 2019. An architectural view for data protection by design. *IEEE International Conference on Software Architecture (ICSA)*, pp. 11-20.

Spurr, A., Ausloos, M., 2021. Challenging practical features of Bitcoin by the main altcoins. *Quality & Quantity* 55, 1541–1559.

Stoll, C., Klaaßen, L. and Gallersdörfer, U., 2019. The carbon footprint of bitcoin. *Joule*, *3*(7), pp.1647-166

Swanson, T., 2018. How much electricity is consumed by Bitcoin, Bitcoin Cash, Ethereum, Litecoin, and Monero. *Great Wall of Numbers*. [Accessed: 27/04/2023].

Swan, M., 2015*. Blockchain: Blueprint for a New Economy. NYC: O'Reilly*.

Tang, H., 2019. Peer-to-Peer Lenders Versus Banks: Substitutes or Complements? *The Review of Financial Studies* 32(5), 1900–1938.

Tatar, U., Y. Gokce, B. Nussbaum. 2020. Law versus technology: Blockchain, GDPR, and tough tradeoffs, Computer Law & Security Review, 38, 105454, https://doi.org/10.1016/j.clsr.2020.105454

Taylor, P.J., Dargahi, T., Dehghantanha, A., Parizi, R.M. and Choo, K.K.R., 2020. A systematic literature review of blockchain cyber security. *Digital Communications and Networks*, *6*(2), pp.147-156.§

Thakor, A. V., 2020. Fintech and banking: What do we know? *Journal of Financial Intermediation* **41**, 100833.

Truby, J., 2018. Decarbonizing Bitcoin: Law and policy choices for reducing the energy consumption of Blockchain technologies and digital currencies. *Energy research & social science* **44**, 399–410.

Tschorsch, F. and B. Scheuermann, 2016. Bitcoin and beyond: A technical survey on decentralized digital currencies. *IEEE Communications Surveys & Tutorials* **18**(3), 2084–2123.

Underwood, S., 2016. Blockchain beyond bitcoin. Communications of the ACM 59 (11), 15–17.

Urquhart, A., 2016. The inefficiency of Bitcoin. *Economics Letters* **148**, 80–82.

Vasek, M. and Moore, T., 2015. There's no free lunch, even using Bitcoin: Tracking the popularity and profits of virtual currency scams. In *Financial Cryptography and Data Security, Revised Selected Papers 19* (pp. 44-61). Springer Berlin Heidelberg.

Vives, X., 2019. Digital Disruption in Banking. Annual Review of Financial Economics 11, 243–272.

Voigt, P., and von dem Bussche, A., 2017. Scope of Application of the GDPR 9--30. The EU general data protection regulation (GDPR). Springer.

Vukolić, M., 2016. The Quest for Scalable Blockchain Fabric: Proof-of-Work vs. BFT Replication. Lecture Notes Computer Science, book series (LNSC, 9591), pp. 112-125.

Wang, W., Hoang, D., Hu, P., Xiong, Z., Niyato, D., Wang, P., Wen, Y., Kim, D., 2019. A survey on consensus mechanisms and mining strategy management in blockchain networks. IEEE Access. 7, 22328—223

Wasim A., R., Hasan, H., Yaqoob, I., Salah, K., Jayaraman, R., Omar, M., 2021. Blockchain for aerospace and defense: Opportunities and open research challenges. Computers & Industrial Engineering 151, 106982.

WEF, 2019. Central Banks and Distributed Ledger Technology: How are Central Banks Exploring Blockchain Today? White paper, World Economic Forum. [Accessed: 27/04/2023].

Wheelock, D. C. and P. W. Wilson, 2012. Do Large Banks Have Lower Costs? New Estimates of Returns to Scale for U.S. Banks. *Journal of Money, Credit and Banking* **44**(1), 171–199.

Xu, M., Chen, X. and Kou, G., 2019. A systematic review of blockchain. *Financial Innovation*, *5*(1), pp.1-14.

Yahoo Finance, 2021. Total Number of Bitcoin ATMs Globally Grows to Around 34,000. Yahoo Finance. [Accessed: 27/04/2023].

Yli-Huumo, J., D. Ko, S. Choi, S. Park, and K. Smolander, 2016. Where is current research on block- chain technology?—a systematic review. *PloS one* **11**(10), e0163477.

Zhang, S., Lee, J., 2020. Analysis of the main consensus protocols of blockchain. *ICT express* 6(2), 93-97.

Zheng, Z., Xie, S., Dai, H.N., Chen, X. and Wang, H., 2018. Blockchain challenges and opportunities: a survey.

International Journal Web and Grid Services, 14(4), 352-375.

Zhu, J., Zou, J., Jing, Y., Yao, W., Mo, Y., Zheng, Z., 2022. A Survey of Blockchain-Based Stablecoin: Cryptocurrencies and Central Bank Digital Currencies, in: Svetinovic, D., Zhang, Y., Luo, X., Huang, X., Chen, X. (Eds.), Blockchain and Trustworthy Systems, Communications in Computer and Information Science. Springer Nature, Singapore, pp. 177–193.