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Decentralized Financial Market Infrastructures: Evolution from Intermediated Structures to Decentralized Structures for Financial Agreements

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Financial market infrastructures (FMIs) have evolved as core elements of highly intermediated financial markets partly due to the technological limitations of the time when they were first designed. Organizations and firms were unable to share records without having to entrust a single party to manage them; hence this phenomenon of intermediation has led to significant information silos. Simultaneously, it has driven the structure of business models, as well as regulatory supervision and oversight, in ways that furthered intermediation and also created a misalignment of incentives and risk taking between entities now categorized as systemically important financial institutions (SIFIs) and systemically important financial market infrastructures. Over time, this consolidation has led to highly concentrated FMIs and with it, concentrated risks. Some of these risks go beyond the credit risks of just one or two institutions, becoming instead systemic risks that are continuously monitored by regulatory bodies. Over the past decade, advances in public key cryptography, hash functions, virtualization, distributed consensus, multiparty computation, and peer-to-peer networking have led to experimentation around record sharing between erstwhile competitive firms. Over the past five years, a series of independent efforts has chaperoned regulatory requirements into a digital, automated state that enables secure information sharing in full compliance with the law, while simultaneously enabling market participants to mutualize infrastructure that would otherwise be run by a single trusted party. With these developments, many of the services that centralized intermediaries currently provide could potentially be replaced by decentralized infrastructures or decentralized financial market infrastructure (dFMI). dFMI also enables a change in business structure, where a re-alignment of incentives can take place such that those firms taking risks can fully bear the consequences of these risks.

Keywords: Decentralized financial market infrastructure; financial market infrastructure; systemic risk; central counterparty; digital asset; tokenization.

1. Introduction

Decentralized financial market infrastructure (dFMI) is a new concept built on emergent structural truisms of financial markets, namely:

(1) Money, credit and financial markets make up an international system of interconnected activities between trading counterparts and various supporting actors.
(2) This system is socially useful only if incentives are aligned in such a way that risk is assumed proportionally by those who create it and reap its rewards.[1]

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[1] According to Carstens (2019): "After all, the monetary system is a critical public infrastructure that everyone depends on, and should be run in the interests of the public, not those of private stakeholders. When I refer to 'central bank public goods', this is what I have in mind."

(3) This system admits the existence of public goods provided by entities whose incentives are not primarily financial and whose rewards are reaped exogenously.

(4) The infrastructure that implements 1 can either support or undermine 2.

This paper takes the view that today's Financial Market Infrastructure (FMI) falls short on point 3 because of excessive financial intermediation.

The infrastructure of today's financial markets often facilitates misaligned incentives and results in the involuntary socialization of risk; see Monte and Pinheiro (2018). Hence the current FMI is one where point 1 above has undermined point 2.

The source of excessive intermediation lies in the existing market infrastructures and business models of the key institutions upholding them, particularly for clearing and settlement (C&S) such as central counterparties (CCPs) and central securities depositories (CSDs) which were designed around mainframe (later, client–server) technology architectures. The root cause of this intermediation can be traced to the fact that the business models and market structures we have today are shadows cast by the introduction of electronic data storage and computing models launched in the 1970s (e.g., dematerialization in securities).[2] Whilst information technology brought essential benefits and efficiencies to a market previously based on paper-based instruments, this also disrupted incentive structures and organizational models that were built up over several centuries of market practice and commercial law.

The purpose of financial intermediation was to provide a means to settle the transfer of financial risk during a trade, initially involving physical assets, across space and time, in an efficient and standardized "trusted" way.

While we recognize that it would be remiss to analyze FMI in isolation, in the interest of brevity, we focus on CCPs in this paper, referring to other FMI types as and when necessary. We will, however, change focus in future papers to other FMIs. Numerous authors cover CCPs; see, e.g., Andersen and Pykhtin (2018); Duffie and Zhu (2011); Cont and Kokholm (2014) and references therein.

CCPs brought significant benefits to the markets, such as transparency and standardization, they also facilitated incentive misalignments. The risk of a derivative, for example, is no longer borne by the derivative counterparty, but is partly centralized at the CCP, which is often a too-big-to-fail

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[2] Codified in the Geneva Securities Convention automated at scale, the end result has been intermediation in the value chain between issuance of financial assets and securities, and the subsequent transfer of value between counterparties.

entity whose incentives are not necessarily aligned with those of CCP members. Participants in CCPs, such as banks, take risk onto their balance sheets by giving out loans and mortgages. Clearing members in a CCP provide additional financial resources to cover excess losses incurred by the CCP in unwinding positions of defaulting parties. There is a sense that the risk of catastrophic loss of a single party is borne by all parties.

The dFMI proposal is an attempt to re-imagine how points 1 and 2 above can be achieved as the internet's architecture evolves from client–server to peer-to-peer. Just as IT disrupted market structure in the 1970s by creating a heavily tiered and intermediated system, a peer-to-peer internet will disrupt market structure by collapsing trading and settlement into one process.[3] This can be similarly — maybe even more — disruptive to the system that has reigned for the last four and a half decades, where incentives are aligned such that point 1 above supports point 2.

An example of incentive alignment is a network where management responsibilities and risk bearing remain proportional to risk created. A shared network that provides all necessary functions of existing FMI would be indispensable in order for a systemically stable market to operate. These functions include risk and margin calculations, settlement via delivery and payment.[4]

A fundamental requirement is the existence of widely accessible, credible, regulatory compliant and stable digital currencies, issued by central banks or by regulated private sector institutions, to be used on this shared network. One problem with currently discussed central bank digital currency (CBDC) models is that access to reserve accounts — and the liquidity support that central banks provide to holders of these accounts as a public good — will be the same as today (e.g., limited to domestic commercial banks and some FMIs).[5] As a result, CBDCs envisioned as such will not inherently, directly

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[3]Prior to the 1970s, certain financial infrastructures were more localized, opaque, peer-to-peer, and institutional. Beginning in the 1970s, architecture brought automation, equally broader distribution mechanisms, new products but also intermediation and tiers which were not quite possible in the prior generation. However, this new architecture was also limiting. The latest generation of financial services and infrastructure aims to provide more products to more people in a more sustainable manner. This could result in a less intermediated and more peer-to-peer infrastructure.

[4]An independent central bank is arguably still best to create a unit-of-account and store-of-value. When talking about clearing and settlement, shared ledgers (e.g., a blockchain) can provide a secure medium-of-exchange that is linked to the central bank currency.

[5]See the "money flower" diagram on p. 5 in Löber and Houben (2018). Worth pointing out that many securities settlement infrastructure already settle in central bank reserves (e.g., CLS, Crest, T2S, ASX, Takasbank). See also Löber (2019).

solve many of the problems with CCPs and collateral swaps because the foreign financial institutions and non-bank institutions involved may still be unable to hold a settlement asset like a CBDC. Expanding the role of central banking activities into new spheres of digital finance, while is outside the scope of this paper, could be a key development.

This paper explores the past, present and future of FMIs as a pathway toward dFMIs. This will shape how marketplace participants, regulators and their stakeholders could benefit from the adoption of technology that enables safer, incentive-aligned marketplaces with less concentrated risk structures. This is achieved by focusing on post-trade processes in the trade life-cycle within FMI, covering C&S, and specifically discussing CCPs both under the lens of today's capabilities and decentralized technology capabilities. It concludes with a call to action for industry participants to evaluate and explore the potential benefits and challenges of this new paradigm.

2. Current FMIs

2.1. *Background*

As per the Committee on Payments and Market Infrastructures (CPMI) — the International Organization of Securities Commissions (IOSCO) Principles for Financial Market Infrastructures (PFMI), a Financial Market Infrastructure (FMI) is critical to fostering stability in financial markets and the broader economy. These systems facilitate the clearing, settlement, and recording of monetary and other financial mechanisms. In this section, we analyze the functions of a Central Counterparty (CCP) as they have evolved over time. We connect the risk generated in financial trading with the technology that serves to transfer that risk across counterparties, and ultimately, dissipate it upon fulfilment of obligations.

According to the PFMI, the three main infrastructures for this reallocation of risk are:

(1) Central Counterparties (CCP), which perform netting and facilitate value, collateralization pooling, metallization of risk, provide anonymity and ensure that delivery-versus-payment (DvP) takes place as promised. According to the principle of metallization, market participants pool their resources to deal with some members' failure. While CCPs have experienced historical defaults leading to loss of participants due to collateral shortages, over time they have become larger, more organized and thus more important to the financial system.

(2) Central Securities Depositories (CSD), which hold securities to facilitate ownership transfers via book entries rather than physical transfers. They were first set up in the early 1970s, during the transition from paper to electronic trading with the use of mainframes, followed by client/server architecture and now trending toward a more peer-to-peer system.[6]

(3) Payment Systems, which perform settlement services for financial transactions where ownership of an asset is transferred against exchange of monetary value.

The current FMIs operate largely under a system envisioned during and for the industrial revolution, with an initial purpose of facilitating global trade of physical assets. Early peer-to-peer settlement systems have moved into intermediated settlement systems, where centralized parties were established to formalize transfers of ownership and funds. These intermediary institutions are designed to reduce risk by providing the credibility necessary for both buyers and sellers to engage in transactions at a large scale, across borders. With the development of capital markets, this system came to manage trades of increasingly complex financial assets. Metallization, along with joint ownership and pooling of funds, facilitates matching buyers and sellers, as well as borrowers and lenders. This saves time, lowers transaction costs and brings economies of scale.

Moreover, centralization facilitates immobilization to safeguard ownership certificates and streamline book entry records. This intermediary-based structure also enabled dematerialization and the substitution of paper-based securities to book entry records. With the introduction of technology through entities such as the Depository Trust Company (DTC), fully electronic bookkeeping further increased the efficiency of trade records.

Yet the very nature of intermediated FMI, which relies largely on mechanisms of pooled funds, also shapes the risk landscape of the global financial market, where losses from defaults can be spread across large groups. When centralized entities function at a scale such that their operations can affect, directly or indirectly, all entities in a system, their idiosyncratic vulnerabilities can produce transmit contagion and pose systemic risk. With C&S processes at the core of interrelated trade relationships transmitting risk in FMI, entities like CCPs are an integral component behind the incentive structures and underlying business models that uphold the current system. Existing C&S mechanisms, particularly the risk structures arising

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[6]CSDs are an example of an intermediary that was totally driven by client–server technology of the day; see also Winn (1997).

from the use of CCPs, set the context for a dFMI proposal to mitigate risks and improve efficiency, in ways that can bring financial services and their governance structures up to speed with the latest advances in computation and technology.

2.2. *Central counterparties*

CCPs existed but were structured differently throughout the 19th century in comparison to today; see Kroszner (2006). For instance, paper-based instruments were a P2P form of C&S. Over a century of common law preceded the immobilization and dematerialization of financial assets in the 1970s, which brought about functional changes to C&S.

Clearing Houses (CH) were set up to reduce the cost to transact commodities and derivatives for their members. By providing shared services, such as margin calculation, netting, and monitoring solvency of its members, a CH provided these members — and its associated exchange(s) — with protection from the administrative burden of fulfilling their obligations, along with a substantial surety that their counterparties would be solvent.

The pace of change has accelerated with the advent of computers in the form of client–server architecture; see Madnick (1998). This has created an ecosystem of data transfer in which not only are data storage and collection centralized, but also large parts of global computing power are aggregated.

Usage of computers to support the processing of data evolved continuously to support changing business mores. Single-user mainframes and time-shared systems were capable only of supporting batch processing at distinct times of the day and hence forced CCPs to impose margins adequate to cover the risks of a full day. Modern systems based on the client–server paradigm run various parts of bigger programs in a distributed manner across multiple "servers", with a speed improvement that has facilitated the spread of lower intraday CCP margin requirements, releasing collateral for other transactions; see Walker (2018).

With the maturation of the client–server topology, data was collected and commoditized by several large platform players. With the advent of cloud computing, scale economies have driven a centralization of market-share, where only a handful of players are now responsible for providing critical parts of the internet infrastructure; see Fratto and Reiners (2019). Without this, the modern internet as we know it would be unavailable. The aforementioned handful of players factored resilience into their systems to satisfy the "always-on" server side of the client–server architecture.

An important category of risks in the financial system comprises post-trade risks. The post-trade period spans the time from "trading" — when participants agree on the terms of a transaction — to "settlement" — when the obligations related to the transaction are discharged through the exchange of assets and/or monies (settlement).

The length of the post-trade period varies among financial instruments. Today's convention for settling FX and securities transactions is $T + 2$, meaning that transactions are settled two business days after trading. Derivatives are typically longer-dated contracts. Many derivatives contracts settle months or even years after trading.

For credit derivatives, for instance, settlement may be triggered by a default event and not by the end of the contract.

One important post-trade risk is replacement cost risk. This is the risk of loss of unrealized gains on unsettled transactions with a counterparty. The resulting exposure is the cost of replacing the original transaction at current market prices, due to the default of the counterparty between the time of the trade and the later settlement.[7] Replacement cost risks increase with market volatility and length of the post-trade period.

Another relevant post-trade risk is principal or credit risk. This is the risk that a counterparty will lose the full value of assets involved in a transaction — for example, the risk that a seller of a financial asset will irrevocably deliver it but not receive payment.

Principal risk may exist in FX, equity and bond transactions. Current FMIs eliminate principal risk by guaranteeing simultaneous settlement of both legs of a transaction. This is called Payment vs. Payment (PvP) for FX and Delivery vs. Payment (DvP) for equities and bonds.

A CCP is intended to mitigate such systemic risk. It interposes itself between the counterparties to the contracts traded in financial markets, becoming the buyer to every seller and the seller to every buyer, thereby ensuring the performance of open contracts. Yet a CCP is not immune to risk. A CCP faces two types of credit risk: current exposure and potential future exposure. Current exposure (CE) arises from fluctuations in the market value of open positions between the CCP and its participants. In order to mitigate risks from fluctuations in the market value of open positions, a CCP pays and collects Variation Margin (VM) from its clearing members. Potential future exposure (PFE) arises from potential fluctuations in the market value of a defaulting clearing member's open positions until its positions are closed out,

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[7] CPMI Glossary 2016.

fully hedged or transferred by a CCP following a default. For example, during the period in which a CCP closes out a position following the default of a clearing member, the market value of the position or asset being cleared may change. This could increase the CCP's credit exposure, potentially significantly. Initial margins (paid by both counterparties when the contract is made) are calculated to protect the CCP against PFE, with a high probability.

In order to increase resilience against losses from defaulting clearing members, the CCP relies on pre-funded financial resources, which are largely provided by clearing members. These financial resources are expected to cover the default of the clearing member representing the largest aggregate credit exposure for the CCP in case of extreme, but plausible market conditions. The lines of defense of a CCP are often referred to as "default waterfall". CCPs in general are expected to have enough resources to survive the default of a single clearing member, whereas a special sub-class of CCPs, which are designated by regulators as "systemically important," must demonstrate the ability to survive a simultaneous default of two clearing members; see Lipton (2018a).

While the resilience of CCPs has increased in recent years (for instance, through more conservative stress scenarios, or measures in the area of recovery and resolution), it is undeniable that, inherent in the way that they concentrate risk into single pools, CCPs can still potentially jeopardize the stability of the entire financial system.

As will be discussed further in this paper, well-designed distributed mechanisms for CCPs have the potential to reduce post-trade risks in the derivatives markets and central clearing in several areas. For instance,

(1) Current Exposure of CCPs can be reduced by more frequent calculation and faster exchange of variation margins. The former can be achieved by systems that can provide real-time aggregated positions, with enough computational resources to complete more repeated CE calculations. The latter can be achieved by high quality tokenized collateral, such as a "stablecoin", or a "central bank-issued digital currency (CBDC)", usable on modern high-speed payment networks. For the purposes of this paper, a "stablecoin" is defined as a digital representation of either reserves held at the central bank or a CBDC; see, e.g., Duffie (2019); Klages-Mundt *et al.* (2020); Lipton (2019); Lipton *et al.* (2020) and references therein. We emphasize that we are interested in the so-called wholesale tokens designed for B2B transactions. With tokenized collateral, the time gap

between the calculation of the variation margin and its settlement would shrink considerably (if not disappear).

(2) Distributed CCP infrastructures can also calculate multilateral net positions.[8] Just like conventional CCPs, they can calculate multilateral net positions without resorting to a single computational or clearing agent. Variation margins would be exchanged directly between the participants based on the netted positions, eliminating the risk of having a CCP that may be too big to fail. This would greatly reduce risk for the survivors in the case of certain participants defaulting.

CCPs may facilitate liquidity in markets, as their business model operates on timely payments and conversions between cleared assets and non-cash collateral into cash. This mechanism is contingent upon rapid and efficient trades, as well as adequate management of margin requirements. Contracts cleared by a CCP can vary in length, from as short as one day (such as in some securities markets), to upwards of several decades (such as in the credit-default swap market). In cases of liquidity constraints, additional margin requirements may put pressure on clearing members and increase the risk of default, which at a large scale can threaten the financial markets' stability. Below we consider both cases.

2.3. *CCPs in securities markets*

Securities bought and sold on regulated markets are often centrally cleared, which can also occur in over-the-counter (OTC) markets. As mentioned above, in securities markets, settlement is usually at $T + 2$ (there are exceptions), and counterparty risk regards the risk of default over the trade-to-settlement delay. In the case of central clearing, after an agreement between the counterparties, a deal is usually novated into two deals, one between buyer and CCP, and another between CCP and seller. Settlement happens at $T + 2$, for a net amount between each counterparty and the CCP. Interposing CCPs aims at reducing risk by netting, and hopefully by leveraging the better credit quality of the CCP. CCPs manage margins and keep default funds in custody.

In this business model characterized by end-of-day settlement, which is days apart from trading time, notionals are accumulated along the trade-to-settlement delay. Liquidity implications are different in gross versus net settlement arrangements, but in both cases counterparty risk exposures grow over the trade-to-settlement delay, due to both accumulation and adverse

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[8]Would it be a contradiction to add a "d" to CCP, a dCCP?

market movements. In this setting, multilateral netting of short and long positions across as many positions as possible, as obtained via central clearing, is a very important form of risk reduction. Would this be equally relevant if settlement was DvP with a trade-to-settlement delay much shorter than it is today?

The question itself is mostly relevant to instruments which naturally terminate when a transaction is settled — for instance, shares sold for cash or short dated instruments. For more complicated instruments, such as swaps, which have multiple cash flows, further work is needed. This can be performed more easily if replacement risk is disregarded.

2.4. *CCPs in derivatives markets*

Central clearing has become mandatory for a large number of OTC derivatives. According to a relevant report: between 2012 and 2016 the percent of cleared OTC IR derivatives went from 40% to 60%; see p. 9 in Independent Evaluation Office of the Bank of England (2017). After agreement among counterparties, a deal is novated into two opposite deals between the counterparties and the CCP. In the same process, the deal is reported to trade repositories. Counterparty risk in the derivatives market lasts, in principle, until the maturity of the deal, often several years later. Counterparty risk is closed at the moment the counterparty provides sufficient Variation Margin to cover the exposure.

Unfortunately, Variation Margin never corresponds to exposure since it is settled with a $T + 2$ delay (with exceptions), and moreover it corresponds to the minimum between margin call and the counterparty's valuation (undisputed amount).[9] This creates a gap risk which is mitigated by the Initial Margin and default fund. Interposing CCPs aims at reducing such risk by netting, and hopefully by leveraging the better credit quality of the CCP. CCPs manage margins and keep default funds in custody. The fact that these funds are often (but not always) kept with the clearing members themselves is a very important but subtle source of additional risk.

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[9] New practices such as settle-to-market — where banks, instead of posting collateral against the change in market value (i.e., variation margin), make outright payments to restore the market value to zero — have additionally contributed to the observed decline in their market values. For example, settled-to-market (STM) models introduced in 2017 are gaining popularity. The Commodity Futures Trading Commission (CFTC) in Letter No. 17-51 Oct 12 2017 has requested that all CCPs in the US treat Variation Margin as STM. As described by Eurex Clearing circular 120/17, STM transactions are structured such that all outstanding exposure is fully and finally settled daily. This was originally an option only for clearing members on OTC interest rate derivatives but was extended to client-related transactions as well on May 2, 2019 in circular 037/19.

The global financial crisis (GFC) has left its impact on the financial eco-system as a watershed, by irreversibly changing its modus operandi. In particular, both the range of products and the number of trades cleared by CCPs increased enormously, largely due to pressure by the Group of 20 international forum (G20) and its regulators. Given the fact that trade execution, clearing and settlement, constitute the all-important triad for capital market functioning, this increase in range and volume of trades has profound implications. In addition to stocks, many other products, such as equity derivatives, interest rate swaps, commodities and others, which used to trade OTC, have now been moved to exchanges. As a result, *nolens volens*, all large banks are engaged in trading on CCPs.

2.5. *CCPs' benefits*

Advantages of certain CCPs functions are self-evident. They have been tested in the last several years and are not the subject of debate. CCPs "become the focal point for transactions thus increasing market transparency", since cleared transactions can be surveilled by regulators by monitoring just one entity. CCPs reduce complexity, since they set standard collateral rules, leading to standardization of market practices and streamlined processes. CCPs compress exposures by collapsing netting sets for all counterparties into a single CCP netting set, with a sub-additive effect on counterparty exposure.

Other advantages are speculative and have not been tested in practice. They rely on the assumption that a CCP can manage severe default events and survive with no bail-in. No counterfactual events where CCPs have failed have yet occurred — a record that no regulator wants to be the first to break by taking their eyes off the viability of CCPs under their charge. CCPs collect from member banks and keep in custody the default fund, which is a mutual fund that the CCP can use at the end of the default waterfall. This would leave the market unaffected in case of a default by a CCP member. CCPs improve price discovery since they are often treated as risk-free, so that CCP prices are affected by no adjustment related to the counterparty's credit risk (or by a small, homogenous one). CCPs allow business continuity since, when the default waterfall covers the default of one counterparty, and the CCP consequently does not default, the deal with the CCP also survives. CCPs guarantee anonymity of transactions and provide the desirable level of opaqueness in the market.

These functions essentially apply, with different technicalities and different materiality, to both cash and derivatives CCPs. Figure 1 illustrates the above points succinctly. The flow of money, which is not shown in the

Fig. 1. Seller (S) instructs her Broker (SB) to sell a security. At the same time, Buyer (B) instructs her Broker (BB) to buy this security. The exchange matches both brokers, SB and BB. The exchange can be organized in a variety of ways, for instance, as a Limit Order Book (LOB). When the orders are matched, the information is sent to Central Counterparty (CCP = 4), where the trade is novated. As a result, the trade is transformed into a pair of trades: (1) a sale of the security by Seller's General Clearing Member (SGCM = 3) representing the SB to the CCP; (2) a sale of this security by CCP to Buyer's General Clearing Member (BGCM = 5) representing the BB to the CCP. SGCM asks SB to deliver the corresponding security. SB sends this request to Seller's Clearing Agent (SCA = 2), who, in turn, forwards it to Seller's Custodian (SC = 1). As a result, the security in question originally held by SC is now held by BC. Further details can be found in Pinna and Ruttenberg (2016); Lipton (2018b).

diagram, occurs in the opposite direction than the flow of the security from seller to buyer as described above. It is important to note that brokers are not always members of CCPs, and a seller–buyer trade can connect a seller to a CCP.

With legacy technology available, the pursuit of goals such as transparency, standardization, exposure reduction and fund metallization required a very invasive approach. This entailed novating all deals to replace the original counterparty with a single, large institution to manage a "mainframe" trading book, and simultaneously turn into a single point of failure for both operational and financial risk.[10] We believe that current technology allows us to consider decentralized alternatives to achieve the same regulatory pursuits for the benefits of CCPs with less concentration of risk.

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[10]The genesis of distributed Financial Market Infrastructure (dFMI) arose from multiple papers by Feenan, Ram, and Sams including distributed Financial Market Infrastructure (dFMI) and the Disintermediation of Digital Assets.

With the increased range and volume of trades that occurred following the GFC, there is a clear need for banks to assess potential losses due to defaults of GCMs (general clearing members) of a given CCP, as well as defaults of CCPs themselves through the network banks participate in. The interconnectedness of the CCPs, which is due to the linkages through common GCMs (general clearing members), highlights the importance of modeling the network itself for potential vulnerabilities in the risk context of today. The network's entire topology would change after Brexit.

Another special case of risk insurgence comes from cash flow payments. The cash flow payer's exposure jumps when the cash flow is paid. Collateral should have a simultaneous jump by an equal and opposite amount to avoid risk jumping instead. Yet long collateral time-to-settlement makes this impossible.

Ultimately, the CCP business model provides transparency, standardization and the perception of reduced risk thanks to netting. In a context characterized by long times for collateral settlement, and frequent misalignments between margin call and collateral received, netting between as many short and long positions as possible becomes a crucial form of risk reduction. Yet if collateral settlement times were short and misalignments unlikely, including mechanisms to make cash flow and collateral payments atomic, the need for netting, and thus the CCP business model, may be less relevant.

2.6. *CCPs' challenges*

The reason for mandatory clearing after the GFC was to reduce the likelihood of systemic defaults.[11] In order to perform this role using legacy centralized technology, a CCP had to become the counterpart to all trades beginning on day 0. Several years later, the CCP business model has been well tested for this day-to-day, operationally intensive activity of being a counterpart to all trades. Despite the transparency, standardization and perception of reduced risk from netting, if we consider the purpose for which CCPs were created — reducing the likelihood and severity of systemic defaults — their business model is untested, and there remain key open questions about it.

Alignment of interests is a crucial issue at hand: if CCPs' incentives are not aligned appropriately with those of market participants, they may in fact

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[11]Defaults are not merely an academic exercise. The International Swaps and Derivatives Association (ISDA) recently published a paper, which looked at two specific clearing members that have defaulted in the past five years; see ISDA (2019).

become conduits to magnify the very risks they were designed to minimize. If a large default were to occur, would a CCP be effective in managing it? In Bignon and Vuillemey (2020), the 1974 story of the default of a CCP member is described from a regulator's point of view, which signals that in the default event, the CCP's interests were aligned to those of the defaulting party and not to those of the CCP members. This led to a moral hazard and eventually the default of the CCP itself. The authors suggest leaving less discretion in the hands of a central intermediary in order to avoid such distortions in future default events.

Given that CCP performance in a default event is not bulletproof, did we really reduce systemic risk by creating a few even larger points of concentrated risk? In fact, we know this is not to be the case: the default of a CCP would be a more systemic threat than any credit event regarding an individual player, since a larger number of counterparties would be affected, each on a larger portfolio.

Concentrating all collateral in a CCP transforms risk metallization into a threshold risk, whereby once the Initial Margin (IM), Deposit Facility (DF), and CCP's capital is exhausted, the entire market suffers a credit event, not just the counterparts who dealt with the defaulting party. Such a large systemic event involving a CCP could only be brought to an end via bail-out with taxpayer money; otherwise there is no price formation, or market itself (Cox and Steigerwald, 2017).

Recently, regulators have taken measures against this risk, for example (BIS, 2012, 2017): "The arrangements adopted by a CCP should be transparent to its participants and regulators" and "CCPs should also have rules specifying clearly how defaults will be handled."

Due to additional observations on avoiding indetermination in CCPs' default management plans, "ISDA urges regulators and policy-makers to continue working together to finalize unambiguous and predictable CCP recovery and resolution strategies" (ISDA, 2017).

3. Future dFMIs

3.1. *Straw man proposal*

dFMIs are consortium entities whose members are comprised of the main participants in a market, organized in a peer-to-peer model, which is governed by dFMI participants themselves rather than a central intermediary. Governance reflects members' interest in a smooth functioning market, minimizing the occurrence of credit risk and dealing swiftly with risk insurgence.

The Bank of England (2017), recognizes this governance structure and issues recommendations on "governance and assurance" stating the following:

> "In light of our evaluation criteria and assessment, we believe that now would be an opportune time to review governance and assurance, building on the achievements described above, and looking at the challenges ahead. This includes the role of the FMI supervisory committees, how best to harness individual members' contributions, and the role of third-party challenge. We also recommend that Court considers augmenting its annual discussion of FMI supervision." (p. 41)

dFMI proposes a decentralized network of connected nodes representing market participants and collectively responsible for oversight. The issue of possible misalignment of interests between a central intermediary and members can be managed and mitigated by design. By design there is no central intermediary separate from the larger network of nodes representing the interests of the market participants themselves. Market participants interact directly with each other, such that the risk of a transaction is contained within those parties involved in it. In addition, the default risk of the central intermediary, and with it the systemic risk it has historically represented, is purposely eliminated.

dFMIs are based on the principle of metallization, which requires market participants to pool their resources to deal with some members' failure. Because none of the market participants have a central role, they cannot be too-big-to-fail. Consequently dFMIs are about risk metallization (among members) without risk socialization (among taxpayers).

Compared to infrastructures of central clearing through central intermediaries, this decentralized business model reduces risk through several aspects:

(1) Economic: the misalignment of interests discussed in the above CCP default example is replaced by member incentives, which are aligned with their business role.

(2) Financial: operational and credit risk are no longer concentrated in a single central entity, but can be more diversified across the members.[12]

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[12] The qualifying liquid resources (QLR) of the CCPs under European Markets Infrastructure Regulation (EMIR) regulations have to cover the default of any two clearing members, a level that is approximated by the two largest members contributing initial margin defaulting. In a dFMI, parties choosing not to deal with the largest members would not be exposed to their risk.

(3) Technological: the single-point-of-failure of the "mainframe" CCP is replaced by a distributed network. Resilience comes from redundancy of data and processes across the members.

The advantages of dFMI processes over FMI processes such as CCPs are a direct consequence of the change from a centralized to a decentralized business model. Prior to the crisis, while the structure of financial markets was nominally decentralized, the functions of intermediaries were centralized. The consequence of intermediary default due to collateral shortages represented a loss for all participants, likely a chain of ensuing defaults and most importantly systemic risk. dFMIs propose a change to the fundamental architecture of today's financial system, around a rearrangement of the structures behind systemic loss and trust.

dFMIs can fuse together the advantages of a decentralized market structure with the functions of CCPs, such that the public confidence in CCP capabilities can be met with the right alignment of interests. Investors dependent on the proper discharge of CCP functions would ultimately assume a level of risk that more accurately accords to their level of risk aversion.

While much of the financial system still runs on legacy systems, a dFMI would be built around modern technological advances that facilitate, streamline and increase the security of operations. Following the mainframe and minicomputer eras — between the 1950s and 1970s — there have been continued advances in technology including involving cryptography, distributed ledgers and additional automation. Together these support a much needed change in market structure and business model through dFMI.

3.2. *Clearing and settlement for dFMI*

The evolution of client–server technical architectures to peer-to-peer technologies through blockchain technology allows for direct and real-time C&S. There is no need for a centralized counterparty to manage and provide credibility during a delayed C&S process of T + 2 or longer times, or the legal and governance implications during the days it takes to transfer ownership of assets, where ownership titles can be unclear.

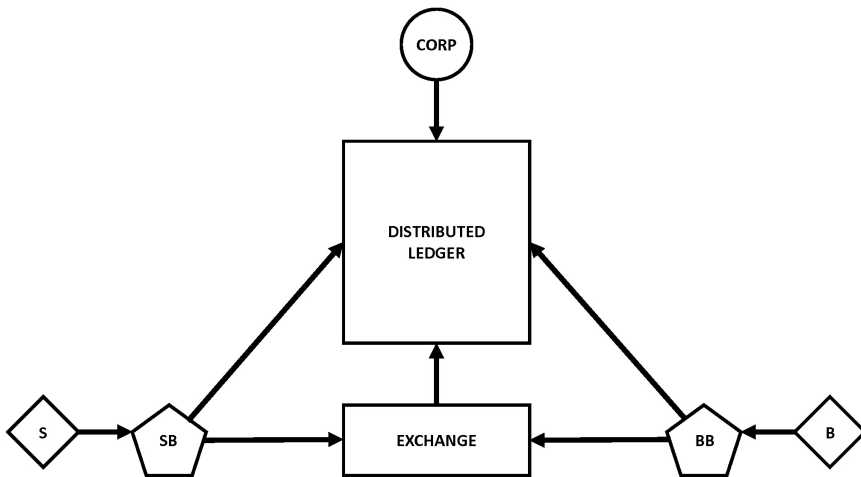With direct and shorter settlement times, dFMI allows greater transparency and efficiency; see Fig. 2.

Fig. 2.   Functions of most agents are replaced by the power of distributed ledger.

3.3. *Functional decomposition of dFMI for central counterparty activities*

How can dFMIs perform functions similar to CCPs? dFMI mechanisms are designed to ensure that one party's default will only affect its direct counterparties and not the entire market. In the event of a major default, this eliminates the risk that a default fund from member banks, as utilized in the CCP context, may not have enough resources at the end of the default waterfall. The default of one market participant would not affect the market as a whole, regardless of the depth of a default fund's resources. This provides not a partial degree, but essentially a full degree of security against contagion.

As for price discovery, some dFMIs would record offers (bids and asks) as transactions on a blockchain, which are immutable, transparent, real-time, and available to all participants in a network, even if a node may fail. This design pattern would be applicable to both conceptual central order books and request for quotes type markets.

This is contingent upon a properly functioning market infrastructure with no technical or service disruptions. For CCPs, on the other hand, netting sets compress exposures into a single netting set, which reduces the risk in addition to the use of a default fund mechanism. The resulting perception of CCPs as being risk-free adds to the overall credibility of CCP prices. These prices are not subject to adjustment for counterparty credit risk, and thus foster transparency and price discovery as long as the CCP is functioning correctly.

Moreover, dFMI ensures business continuity more fully than CCPs. dFMI has resilience built into the core of its design, so there is no need to rely on a separate and limited pool of funds that may not be sufficient enough to cover a certain scale of losses. Risk exposure is inherently contained between two direct counterparties transacting with each other, which bear the risk and also the consequences of potential default. CCPs merely enhance business continuity by relying on the default waterfall to provide resilience to the system in the case of one counterparty's default. If a CCP can survive despite a member's default, so can a given deal survive with the CCP.

Finally, dFMI provides anonymity inherent to the blockchain infrastructure on which it operates, without compromising on transparency or the dynamics of efficient markets. CCPs require a more complex approach to ensure anonymity, with implications on other market dynamics. By acting as a counterpart to every trade, CCPs ensure that trading partners remain anonymous to each other. Clearing members do not need to worry about the creditworthiness of their trading partners and are free to trade with any other CCP members. Yet the downside risk of this system is that if one trading partner faces a liquidity constraint, such as borrowing a large sum of money or making a large investment, the market will not turn against it thanks to the CCP's perceived risk reducing role, maintaining high levels of liquidity.

3.4. *Potential benefits of dFMI over CCP functions*

3.4.1. *Default fund metallization*

As mentioned above, dFMIs are consortia where members also operate the nodes of a distributed network working on a ledger where global state is shared; commonly referred to as a blockchain.[13] On such a blockchain network, digital resources can be mutualized with no need to find a central, third-party administrator to take custody of the assets. Assets can be pooled at an account controlled by a smart contract that can only be modified via multisignature. This ensures that only a qualified majority of the members has control over the resources. "Smart contracts" and decentralized applications can be used to create "unambiguous and predictable" rules for the

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[13]Not all "blockchains" that are promoted as "blockchains" are an actual blockchain. Some in fact, are centralized and/or proprietary shared databases. For the purposes of this paper, a blockchain consists of peer-to-peer nodes that validate and manage a global state shared amongst all participants in the form of blocks, or containers filled with transactions; the protocol of which is open-source and not governed by a single organization.

release of funds, including automatic rules that make mutualized funds available in case of credit issues, following a codified waterfall where risk participation is proportional to risk creation.[14]

Such smart contracts can also be used for Initial Margin, which cannot be re-hypothecated and must remain segregated from the control of either party.[15]

In a peer-to-peer business model, an entity that is counterparty to every deal just in order to pool resources and construct a mutual fund is unnecessary. Mutualized, loss-absorbing capital in a purely bilateral model could exist, for instance, in the form of a cash fund to cover potential losses from cybersecurity breaches, theft, execution errors, or counterparty defaults. This would provide investors added comfort regarding business continuation and overall stability of an underlying trading system. Technology today can lower multilateral contracting and monitoring costs dramatically, making this approach much more practical than it once was.

Moreover, metallization can be more directly tied to the alignment of incentives among participants in a dFMI context, where the consequences of risk taking are contained among the participants of a transaction. Fee structures can be contingent upon the amount of capital contributions, as directly proportional to risk taken by individual participants. Mutualized capital contributed by investors remains linked to the outcomes of their decisions. This incentivizes responsible behavior more directly than in a CCP context, where mutualized capital is deposited with a central party that will spread risk regardless of the individual contributor's risk level.

3.4.2. *Credit risk reduction*

dFMIs operate on a settlement platform that uses a digital currency, where settlement takes place at the moment a consensus algorithm is

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[14] "Smart contracts" are best described as "transactional scripts" or "persistent scripts" (Cohney and Hoffman, 2020).

[15] What happens if the majority refuse to sign? In one implementation, the only signature is at inception, then the smart contract follows what is written in the code. The parties cannot do anything else because the smart contract controls the Initial Margin. This is in line with regulations requiring Initial Margin to be segregated. In current regulations, the Initial Margin is not really under your control, unlike Variation Margin. This can be done with smart contracts rather than only custodians, lawyers and liquidators. A qualified majority always needs to have the possibility to change the smart contract, for errors or changes in the rules, that is what multisig is for. But the party whose initial margin has to be used cannot withdraw it.

successfully executed.[16] The consensus algorithm proves the (Byzantine fault-tolerant) agreement of a qualified majority of validators and runs in real time.[17] This new business model minimizes trade-to-settlement time from days to hours, such that counterparty risk exposures do not accumulate but can amount for only a fraction of what they represent in FMI given current settlement delays. Rather than relying on a hopeful assumption that a CCP is risk free, this system reduces credit risk based on an objective, measurable criterion: shortening the delay between the opening of a credit exposure and its close, by means of a deal or margin settlement.[18]

Collapsing the trade-to-settlement delay to a very short time can reduce risk dramatically when coupled with DvP arrangements. The latter feature can be obtained without central intermediaries, using instead escrow smart contracts or other cryptographic techniques. The networks ensure that payments are triggered only if the securities are actually transferred, and vice versa. On-chain digital currencies can also be used to reduce operational risks and improve intra-day liquidity.[19]

Moreover, price discovery also improves when counterparty risk is negligible for all parties over a very short settlement delay. This phenomenon currently occurs in the overnight market, where banks can lend money to each other at a standard market rate, since a short lending maturity (less than 24 h) makes their credit risk homogeneous and very low. This was discussed in a related topic around a hypothetical "narrow bank"; see Levine (2019); Lipton *et al.* (2018).

In the case of derivatives, risk is reduced by shortening the interval between measurement of exposure and settlement of the corresponding collateral update, as well as by making collateral updates much more frequently than in FMI. Collateral rules can be codified through precise software implementation, reducing the scope of misalignments, automating cash flows and corresponding collateral updates and providing for automatic covenants in case of non-performance. The tools to achieve this reside in the concept of "smart contracts," either at layer 1 (all the business logic is on the

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[16]Based on recommendations from the PFMIs (central bank money) and in this case, a central bank digital currency.

[17]The main benefit and purpose of using a BFT system is to operate under the assumption that a minority may become malicious.

[18]The confidence of a bail-out as a back-stop has been used to justify this.

[19]Would this require excessive collateralization? With much shorter settlement cycles, collateral required is less not more. However, this is a model which requires more pre-funding. See also Smart Margin Calls from Synechron.

blockchain) or at layer 2 (the blockchain works more as a settlement platform and a guarantee of correct execution).[20]

In this new business model, risk of default may be sufficiently reduced so as to make netting of a large number of long and short positions less crucial. This could surely become a replacement of today's system of counterparties, operating with a centralized third-party collector of systemic risk.

3.5. *Business continuation guarantee*

When a counterparty defaults in a dFMI, there is no CCP in between to spread the losses across the entire system in the event of insufficient recovery resources. Therefore, dFMI aims to function within a business model where default can occur among individual entities, with minimum or even no losses for the other counterparties. This is made possible by the short settlement delay, and the ability to automate covenants when one party does not perform.

dFMI provides no business continuation guarantee as in FMI. Deals are terminated (in case of derivatives) or cancelled (in case of securities) with little or no credit risk, and there is no replacement deal. Margin can cover replacement risk, which refers to the risk of denying the non-defaulting counterparty the gain from the canceled transaction. Yet a certain degree of liquidity risk may remain, since the derivative or the security removed could have been instrumental to other deals. A typical covenant in the case of non-performance requires deal termination and the application of initial margin, from the counterparty and network default fund, to cover the (already much reduced) loss arising from market movements.

This business continuation concept for dFMI opens yet another possibility: the concept of systemic default as alien to dFMI, so that dFMI members have no legal recourse on the assets of a non-performing party beyond the resources provided by the counterparty or pooled by the dFMI itself. This would make dFMI a market system unable to generate or spread systemic risk, opening a totally new era for financial markets.

Yet does a lack of systemic loss, necessarily result in systemic stability? In a liquid market, there is no systemic concern, since replacing a counterparty is not difficult. A parallel scenario for FMI refers to the imbalance that a CCP

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[20]It bears mentioning that definitionally there is a difference with how advocates of anarchic blockchains (such as Bitcoin) market "Layer 1" as a "settlement layer". Proof-of-work-based cryptocurrencies — by design — lack the necessary functions to provide definitive legal settlement finality; see Swanson (2016, 2017).

would suffer when a counterparty defaults, which gets diversified away across different counterparties with no systemic concern. In practice, this imbalance could be even smaller for securities, since it is not spread across a long leg between trade and settlement; see Devriese and Mitchell (2006).[21]

This underlying liquidity requirement could be enhanced by additional measures to further ensure systemic stability. Guarantors specified by members can replace them in case they drop out of a deal. For derivatives, the imbalance could even be covered by the dFMI members themselves, through novation of defaulted portfolios.[22] As BIS (2012) states: "in markets where a CCP does not exist, a guarantee arrangement may provide market participants with some degree of protection against losses from counterparty defaults".

In case of dFMIs, the guarantee would apply mainly to liquidity risk, since the above arrangements cover principal and replacement losses. Referring again to BIS (2012), "replacement-cost risk is the risk . . . the cost of replacing the original transaction at current market prices. Principal risk is the risk that a counterparty will lose the full value involved in a transaction, for example, the risk that a seller of a financial asset will irrevocably deliver the asset but not receive payment".

As mentioned above, automated covenants can be set up to ensure market functions in the case of a non-performing party. The strawman model shows how a collateralized derivative can be implemented as a smart contract; see Fig. 3. The smart contract is authorized to transfer Variation Margin from the wallet of one party to that of the counterparty. Meanwhile, the Initial Margin remains under direct custody of the smart contract, in line with regulations requiring it to be segregated from the parties. The smart contract has a 2-of-2 multisignature architecture, so that it can be modified upon agreement from the parties, and not by a single party. This is an example of how multisignature can implement joint custody of an asset, in this case the Initial Margin.

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[21] Devriese and Mitchell (2006) state: "If technology could allow for real-time settlement, for example, participants would not need to form expectations about their cash and security holdings. Although settlement failures in response to a major disruption would still occur, multiday contagion effects would no longer arise."

[22] The primary point of decentralization is contractual: your counterpart is still your trading counterpart, not novation over to CCP. In dFMI this remains bilateral rather than trilateral. Having a single counterpart face everyone in the market means that failure of that counterpart can cause a financial crisis.
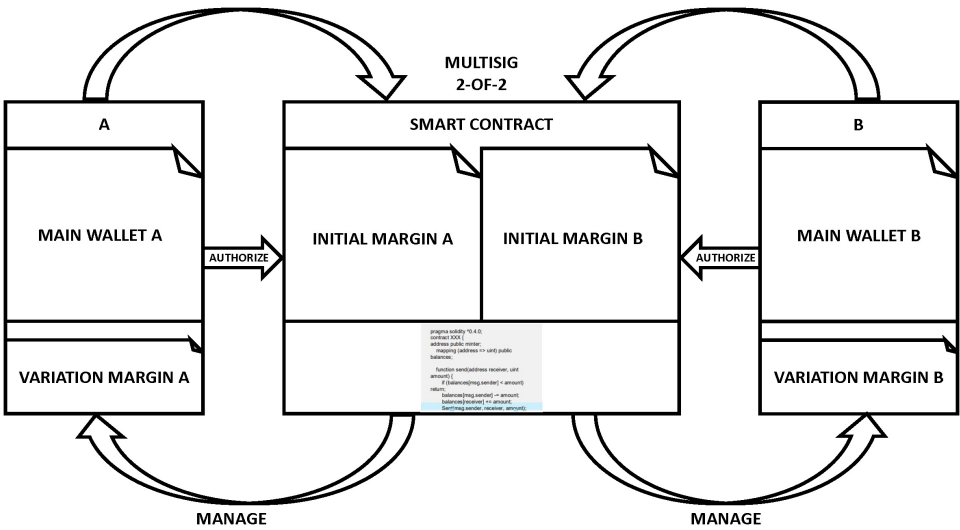
Fig. 3. Smart contract used to execute an exchange between Parties A and B. Further details are given in Morini (2018).

3.6. *Market transparency*

A dFMI is built upon a real-time shared ledger, and can apply cryptography in order to modulate the visibility of its contents to the public and to relevant authorities. A global settlement ledger where changes to the state of all accounts are reported at a level of detail which is sufficient to recreate the underlying transactions provides transparency, promoting market integrity and facilitating surveillance. It can significantly reduce the burden of FMIs to provide data via a plethora of reports that have shown to be inefficient, corruptible and difficult to reconcile.[23]

As described earlier, this record is shared by consortium members, each of which confirms the validity of each subsequent mutation to a ledger's state. The ledger does not violate privacy laws, since both counterparties and value

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[23] According to Osiewicz *et al.* (2016): "Around 85 data fields are to be reported for each transaction...Such a wide-scaled and detailed reporting implies huge data volumes. Over the first year of reporting, almost 10 billion of records were received and processed by the six TRs in Europe...the heterogeneous landscape in TR data provision and non-standardised data collection pose significant challenges for regulators accessing and analysing the data...any meaningful data aggregation requires the reconciliation of the information between the duplicated trades...the other data fields submitted by the two counterparties very often do not match, which raises the question which of the two to keep in the final database with de-duplicated trades. Even for trades reported to the same TR, there can be significant discrepancies for variables such as execution timestamp, price per contract or notional value."

exchanged are shielded by proven cryptographic techniques, which allow encrypted data to be verified without the need to see it in the clear.[24]

Transparency toward the public can exert a normalizing influence on fees and charges — and improve efficiency due to the threat of competition. For example, a dFMI can enforce norms such as a consistent approach to disclosing trading fees, providing certainty regarding the cost of trading. Without a dFMI consortium, entities such as trading platforms in the retail market for digital assets may choose not to disclose their fees or to hide them within the margins charged for digital assets themselves.

The provision of high quality, timely and granular information about transactions to the authorities facilitates ease of compliance to modern mandates for reporting such as those imposed on cleared OTC derivatives. For the regulators, if such information is taken directly from a common source system of record instead of being obtained at lower frequency through indirect systems, surveillance can be conducted in a more direct manner.

The new operating model for a dFMI based on the use of a shared ledger provides for tailored levels of access — instead of requiring third parties to slice and dice aggregated datasets into specific segments for reporting to different regulators based on their various geographical or industry mandates, it is possible to selectively mask portions of the ledger directly from certain parties based on cryptographic keys. This capability reduces the scope for mistakes being made by third parties in the pre-processing of data for presentation to the regulators, and allows for errors found to be corrected back at the source — which benefits all other users of the same data source.

3.7. *Standardization*

The standardization brought by CCPs is largely derived by the metallization of a collective process led by market members. According to BIS (2012), "in certain OTC derivatives markets, industry standards and market protocols have been developed to increase certainty, transparency and stability in the market. If a CCP in such markets were to diverge from these practices, it could, in some cases, undermine the market's efforts to develop common processes to help reduce uncertainty."

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[24] These techniques include, but are not limited to, obfuscation techniques, zero-knowledge proofs (including bulletproofs), mimblewimble, and homomorphic encryption. Certain hardware-based solutions, like SGX, are not considered fully reliable at this time due to continual exploits and compromises.

The main effect of CCPs has been to codify a set of standards into a single rule that applies to both parties in a transaction. With a centralized solution, standardization was ensured to be immediate across all participants. dFMIs are conducive to the same form of standardization, since all players participate in the same network and agree on the smart contracts that regulate their business. Standardization, in this case, builds upon a network of bilateral agreements, leading to a domino effect toward global standardization, where potential diversification of approaches can make markets more resilient. Different players are incentivized to interact and interoperate, and thus need consistency in their interactions with a dFMI platform, which will favor a single standard of operations.

Price discovery is a key aspect that dFMI favors by promoting reliable operations and services that ensure functionality, transparency, and if needed, cash reserves for purposes akin to regulated FMI marketplaces. Otherwise, arbitrage as seen across certain digital asset exchanges can arise due to operational inefficiencies such as temporary service outages and restrictions on access to trade, withdraw or deposit funds. Outside of a dFMI consortium, trading operators trading on their own behalf within their own platforms may provide liquidity at the expense of conflicts of interest that could hinder the integrity of markets. Front-running customer order flows, price manipulation, inflating and deflating prices are practices that would undermine price discovery, which dFMI standardization measures would mitigate.

3.8. *Multilateral netting*

We have seen above that a dFMI reduces credit risk by shortening settlement delays, enforcing atomic swaps, reducing misalignments and pooling resources. While payment or exposure netting with a single counterparty can also be customary for dFMIs, multilateral netting is not part of the native features of dFMIs because trading remains bilateral. With a CCP, multilateral netting and compression are by-products. Two opposite positions with two counterparties B and C cancel out when B and C are collapsed into a single party. Netting and compression are also achievable in a system without a CCP. dFMIs can facilitate this process by performing computations collectively and bringing to consensus the correct result.[25] In a dFMI, all deals take place

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[25] There are several ways to get the computations done without a CCP. One can use verifiable computations and trusted execution environments. In this case, one or several machines only execute the pre-agreed code and everyone can verify it via proofs "similar" to digital signatures. There is still some "trust" in the technology, but not the reliance on a central entity fully responsible for computations.

through the ledger, and netting rounds can be computed by members through multilateral offsetting of gross obligations. This provides compression ratios of multilateral netting but a much lower amplifier in the case of default: only the counterparts to the defaulting party suffer a credit event, whereas everyone else in the offsetting cycle only suffers a liquidity event.

Moreover, netting in a dFMI context could solve potential conflicts of interest that exist in CCPs. Computations require knowledge of the global state of contracts, which is usually private information of the parties.[26] Today, netting is allowed only for members trading directly with the CCP, so the CCP not only knows of all the deals, but is also a party to all the deals. As an alternative, related technology for sharing data for computation without revealing private information consists in using trusted execution environments, where computations are performed in private enclaves.[27] In principle, regulated entities, such as trade repositories, already have access to the global state of contracts required for multilateral netting. This technological layer allows multilateral netting without the risks intrinsic to having single third-party entities responsible for data privacy and security, while simultaneously guaranteeing correct netting computations. In a dFMI, on the other hand, a trusted third party may perform the computations required for multilateral offsetting, without becoming a party to all deals. This is already possible with the current framework.[28] Furthermore, today's financial cryptography offers methods to perform encrypted computations on data that remains private even when shared. Cryptography solutions include obfuscation, zero-knowledge proofs and/or multiparty computations.

For most derivatives, computations involved in netting are very complex, and thus not applicable for immediate standardization. The above dFMI solutions are likely to reach scale for securities trading sooner than for derivatives trading.

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[26] It bears mentioning that several platforms that market themselves as "blockchains" but are unable to share state amongst all participants should not be classified as an actual blockchain. See also Walch (2016).

[27] "A Trusted Execution Environment (TEE) is a hardware based technology that executes only validated tasks, produces attested results, provides protection from malicious host software, and enforces confidentiality of shared encrypted data," Enterprise Ethereum Alliance Off-Chain Trusted Compute Specification V1.1.

[28] MiFIR Recital 8: "Portfolio compression may be provided by a range of firms which are not regulated as such by this Regulation or by Directive 2014/65/EU, such as central counterparties (CCPs), trade repositories as well as by investment firms or market operators." (emphasis added).

3.9. *Cross-margining agreements*

dFMI is much better suited than a CCPs to pool capital across entities to prevent losses, as defined by cross-margining agreements. According to BIS (2012), a cross-margining agreement is an "agreement among CCPs to consider positions and supporting collateral at their respective organizations as a common portfolio for participants that are members of two or more of the organizations."

Maintaining enough collateral to absorb risk is key for the survival of CCPs. Yet there have been incidents where insufficient collateral caused default losses to spread. An important historical example of this is in energy clearing, where the default of one participant resulted in an unsuccessful auction: a turn of events that was altogether unanticipated. For a Norwegian power trader, the costs to replenish the default fund were staggering, at over 100 million euros (Ewing and Schreuer, 2019). Scenarios like this bring to question the role of the CCP. In theory, one potential strategy for CCPs could be to pool resources together with cross-margining agreements. Such agreements are strongly favored by regulators, and yet they are not frequent among CCPs (likely due to their resistance to interoperability, as discussed in the dFMI challenges below). This is unfortunate since cross-margining agreements are of crucial importance for reducing systemic risk.

Moreover, exposure compression within separate markets may not reduce global exposure if deals are allocated across markets without coordination.

In a dFMI model, exposure compression scales to a global level more easily than in a central clearing model.[29] Different dFMIs can interoperate and merge without changing their governance model, unlike CCPs. As a result, this can open new scenarios for managing and preventing systemic risk.[30]

3.10. *Potential challenges*

3.10.1. *Regulatory oversight*

Arguably the main challenge to implementing dFMI at scale is the level of regulatory complexity we currently face, both within and across different

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[29] ESMA/2014/1569, p. 441: "Multilateral compression is usually a service provided by a third party service provider within a legal and contractual framework that applies to all participants in the compression."

[30] A strawman decentralized clearing network (DCN) could start with the creation of a DCN via a single private key that manages the contract. This could be seen as the operating company and can refer legacy infrastructure (such as an RTGS). In terms of governance, more autonomous governance models could be set up, to be owned by the constituent members. These could be similar to decentralized autonomous organizations (DAOs).

jurisdictions globally. Several blockchain trading platforms have either chosen not to comply or remain unprepared to comply with US securities laws at a state and federal level. These platforms often take less responsibilities for consumer protection in comparison to regulated mainstream exchanges. With regard to the risk of money laundering and illicit activity, they may not be equipped to verify the origin of funds, so as to confirm trades are "clean". Nor do they provide trading protections common in FMI contexts, such as liquidity reserves.

Consumers and public entities may not be able or willing to conduct trades in the absence of pre-established protections such as liquidity reserves, which in turn could affect low levels of confidence and adoption of dFMI. They may demand a level of regulatory safeguards for trading on dFMI systems that is parallel to the safeguards in FMI fiat and securities markets. To meet customer expectations, dFMI must tackle this issue if it aims to achieve scale in the financial system.

Moreover, managing and regulating a consortium of players presents additional complexities over regulating a single intermediary entity. On a network level, dFMI would have to comply with regulations in multiple jurisdictions, which may present certain contradictions in their requirements. Yet dFMI can cooperate with authorities by leveraging transparency with regulators, which, as stated before, can be observer nodes in the network. It can also be helpful to keep a white list of anti-money laundering/know your customer (AML/KYC) checks off-chain.

3.10.2. *Standardization*

dFMI can incentivize widespread standardization due to the connectivity and interoperability they support across market participants. Yet this presents challenges in implementing consistent norms on a global, cross-jurisdictional level, especially when local standards and regulations may contradict each other. Standardization for dFMI thus becomes less drastic than for FMI, such that different approaches to operations may coexist within a broader network. These differences need to be accounted for in ways that will not hinder the consistency of processes, especially for cases of disputes.

In FMI, standardization is imposed by each vendor to its clients. Some approaches are more effective, and some less. dFMIs cannot follow this model, as there would not be a need to follow a specific vendor and its interests while defining standards. Yet private entities, such as the myriad of FMI intermediaries, imply regulatory boundaries that limit the scope of market

coverage for standardization: an issue no longer relevant for dFMI because the role of third parties would be replaced by market participants themselves.

Thus standardization for dFMIs adjusts to be both more adaptable to the needs of specific members' activities and more easily adopted by broader networks of connected nodes relative to the current CCP context. dFMIs represent a more easily prevalent yet less radical form of standardization: two parties may want to regulate their netting with a different model than the average norm, approved by other parties sharing the management responsibilities of a particular ledger or network.

Because standardization is partial and less immediate than in the CCP case, it can lead to uncertainty in the regulatory realm. Therefore, off-chain and legally enforceable contractual agreements would be better suited to establish the rights, benefits and obligations of participants, rather than solely relying on source code, the underlying blockchain or network attributes. The latter technical attributes should be consistent with the contractual agreements, which provide clarity for business operations to ensue. This also allows for flexibility, analysis and discretion where necessary in the application of rules on a case-by-case basis.

3.10.3. *Joint computations and privacy*

In the absence of CCPs, there are no other operating frameworks that reliably provide privacy and multilateral netting at the same time. One particular advantage of the CCP structure is that it provides obfuscation services: a member of a CCP will not know other members' positions. Moreover, as CCPs have increased in size and importance over time, along with their underlying systems to provide services, greater risk carried by these third-party entities translates into a greater level of commitment that better aligns their interests with those of market players.

It is possible to perform multilateral netting without CCPs, but doing so presents important challenges. dFMI structures can perform the same level of multilateral netting that currently requires a central party. Yet while the technology available today for providing multilateral netting could be made available for dFMIs, they would still have to perform the same replication and flows without CCPs. Implementing this could be a challenge for dFMI, in a way that multilateral netting also implies concentration risk and model risk.

Yet as discussed before, CCPs are also not as bulletproof as they can be assumed to be because FMI structures operate upon placing risk on a third party whose interests at their core are not aligned with those of market players. The design of a CCP-based structure does not fully guarantee

incentive alignment with market players. Furthermore, regulators' interests may not perfectly align with those of CCPs, market members or core elements of financial stability. For instance, while members want choice, regulators want transparency and market stability. CCPs, on the other hand, are ultimately for profit entities, often publicly traded companies which derive revenue from the need to provide services like risk modeling and operational efficiencies.

Implementation of dFMI functionalities could help provide the benefits of CCPs in this realm to market participants, in a way that better aligns incentives across stakeholders.

3.10.4. *Collateral management*

We have seen the advantages of dFMI, specifically Decentralized Clearing Networks (DCN), in operating automatic covenants, holding initial margin segregated from the accounts used for variation margin, moving collateral, standardizing computations and ensuring collateral movements on par with derivatives cash flows. Yet implementing such a model for derivatives is complex because the time to maturity of derivatives can be several years or even decades. Moreover, counterparty risk from trade to settlement can be extensive and long, and can also involve changes in regulations, disputes and restructuring. dFMIs need oracles for computing collateral amounts, a digital currency with settlement finality, and appropriate changes to regulations, regarding in particular collateral management at default. dFMIs for cash products share some of the same challenges. As a result, these operations eliminate discrepancies of cash flow payments, as addressed by a number of papers. Overall, DCN utilities can be much more elaborate for long-term collateral management, as opposed to short-term spot cash products.

3.10.5. *Metallization of capital*

Metallization of capital in a dFMI context would imply proper alignment of incentives, which is key in order to ensure the completion of deals and the greater sustainability of dFMI over time. While different mechanics that apply to derivative CCPs can be factored into the functionality of blockchain-based dFMI systems, this is challenging.

The FMI business model borrows from a long tradition of centralization of mutualized assets on the books of a third party, while a decentralized model

requires an important change in business models and contracts, still to be detailed.

3.10.6. *Liquidity*

Implementing a decentralized business model for dFMI-based transaction operations would require a certain degree of scale in order to sustain adequate market dynamics, where buyers find enough sellers and lenders find enough borrowers to transact on a peer-to-peer basis. This is the essence behind network effects. Achieving that degree of scale requires alignment of incentives across parties involved, as well as buy-in from participating entities. This may require high-level agreements at an institutional level, as well as technical updates which may take significant time and effort to complete. One example of a challenge toward achieving the right conditions to support liquidity in dFMI could be resistance from existing CCP structures to changes proposed on a regulatory and market infrastructure level. There is also a debate around the utility of tokenization with respect to providing additional liquidity to relatively illiquid assets.[31]

3.10.7. *Implementing interoperability*

While interoperability is crucial for dFMI to scale, this could resurface a long-standing argument between regulators and clearinghouses, placing dFMI at odds with clearinghouses' advocacy efforts against interoperability. This dispute emerged immediately after the crisis and continues to persist today.

While regulators have favored interoperability, clearinghouses have been incentivized to preserve their business expansion prospects and revenue streams in ways that undermine interoperability. They drafted a number of letters and papers to present to regulators, arguing that differences in risk models (different businesses) across clearinghouses would make interoperability risky. For instance, a very large clearinghouse could net many trades internally and create margin efficiencies for its own clients. Another clearinghouse with less clients or less financial instruments traded has a different business model. Therefore, trying to connect these two entities with divergent attributes could create more risk.

One component of this argument involves interoperability in equities markets. In the European Union (EU) there are several cash equities markets:

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[31] Tokenization which is a broad, germane topic, may not be a prerequisite for dFMI, and a number of early initiatives are underway to leverage the benefits stated above in ways that support liquidity levels for digital assets, which may include both tokenized and non-tokenized value traded on a blockchain.

Bob can clear part of his shares in one clearinghouse and the rest in another. He would prefer the two to communicate with each other so that the risk is not segregated which is beneficial to Bob as a client from a margin perspective. While interoperability exists to some extent in the EU, in the United States there is only one clearinghouse. Therefore, some aspects of dFMI could be useful by promoting market competition and implementing an interoperable system. Yet each clearinghouse is incentivized to have all of the business.

The same trend has occurred with derivatives. Just after the crisis, regulators pushed derivatives onto clearinghouses, which readily accommodated. Alice could trade outside of a normal trading venue and agree on a price. The trade was then sent to an exchange, where pre-matched OTC derivatives and later exchanges would send it to a clearing route. Pricing would be agreed upon between Bob and Alice. Many exchanges adopted this route, which would go through the clearinghouse and increase their revenues. It was beneficial for both exchanges and clearinghouses, which had previously operated in vertical silos. Yet while regulators had pushed for improving interoperability for years, clearinghouses argued that this would increase risk rather than decreasing it. IOSCO had tried to promote clearinghouses with derivatives, but clearinghouses replied stating that the risk models and technology used (operational models) between them were too different.

Regulators, on the other hand, eventually favored interoperability precisely due to the risk of clearinghouses becoming excessively large. Over time, regulators continued to advocate in favor of interoperability, based on the fact that clearinghouses were not well capitalized. What is the real endpoint, who provides backing if everything fails?

Clearinghouses are connected to central banks, a development that was beneficial for the short term but could present additional risks for the long term. Moreover, entities were more interested in competing with one another to generate additional revenue rather than maintain the quality of their service. This is a challenge for dFMI, but also shows an additional benefit: reducing the incentives against standardization. Finally, this is yet another example of better interest alignment for dFMI, in this case between dFMI and regulators. Yet given the historical context and potential measures to curb interoperability due to clearinghouse lobbying, dFMI may have to collaborate closely with regulators and ensure the right regulatory landscape to protect interoperability in its decentralized operations.

3.10.8. *Seamless execution of trading-clearing-settlement*

dFMI consortia need to operate on technology that can support high volumes of traffic and rapid trading activities, as observed in mainstream financial markets. Current distributed ledger-based platforms frequently lack these capabilities, and often experience disruption and significant errors when attempting to process multiple simultaneous trade requests. dFMI should propose a structure to prevent the technical issues of early distributed ledgers that have shown to cause exchange outages for the span of hours, errors in pricing, restrictions to users' ability to access their own funds, and poor overall service. One possibility could be to implement custom-built features to support specific markets and dynamics of supply and demand.

Clients may be turned away by the lack of pre-trade and post-trade services, unless dFMI consortia take initiatives to offer them. These services could include analytical tools for decision making prior to trades, as well as trade confirmations, reports, and pricing details after trades. Clients may demand tools they are familiar with in the FMI context, to monitor and manage blotter, positions, and technical analysis strategies.

These added services, while largely off-chain, could enhance transparency and effectiveness while lowering trading risks.

3.10.9. *Centralized intermediation and security*

dFMIs bring a form of disintermediation to many of the functionalities currently conducted by the FMIs. This is primarily through a radical change of the existing business model to support financial transactions, but it does not imply the disappearance of the current FMIs as accountable legal entities. Whenever present forms of market infrastructure generate economies of scale that cannot be replaced in a distributed design, such forms of centralization will remain.

Current regulations define the role of a CSD in maintaining a legally relevant list of who owns each security. Even when these roles become distributed and no longer require a centralized body, additional roles will emerge that still require proper intermediation. Key management and custody are paramount examples. Other tasks may be associated with KYC/AML screening for all account holders, or the possibility for regulators and other authorities to screen the cryptographic obfuscation layer that preserves privacy.

From the standpoint of risk reduction related to concerns of illegal activity, dFMI trading platforms can implement features to make the history of

trades available for trade participants, and upon request by regulatory agencies for the purpose of transaction monitoring. These measures would require discretion in light of the use of private keys and private data.

Customer protection measures are another area that requires a centralized authority to ensure credibility. An inherently decentralized system for CCP functions essentially collapses the space and time between buyers and sellers. Yet when dealing with money transfers and ownership of assets, custodial and fiduciary responsibilities come into play, as well as governance structures to ensure reliability and credibility of operations. This entails adequate collaboration with regulators to ensure a sense of trust and transparency. It also calls for adequate regulations to standardize consistent best practices, as well as the role of centralized authorities to ensure security and credibility that are key for scale, without interfering with direct, peer-to-peer interactions among market players.

3.11. *Automated market makers*

For two tokens TN_1, TN_2 residing on the same distributed ledger, it is possible to design a smart contract capable of making markets between these tokens. Such a contract is called an automated market maker (AMM). AMMs have become increasingly popular over the last couple of years, specifically on the Ethereum network.[32] The idea behind AMMs is simple. Anyone can become a market maker by delivering TN_1 and TN_2 simultaneously in the right proportion to the collateral pool. As time progresses, anyone can remove one of the tokens from the pool by simultaneously providing the other token to the pool. The underlying smart contract defines the exact number of tokens, which are delivered to the pool. While the most straightforward use case for AMMs is swapping stablecoins, exchanging other digitized assets, for instance, a stablecoin against Ethereum, is also possible.

The actual exchange rule has to be coded in the corresponding smart contract. There are several popular choices: the constant sum, constant product, and mixture rules. Several sources cover AMMs; see, e.g., Angeris *et al.* (2019); Egorov (2019); Lipton and Hardjono (2021); Lipton and Treccani (2021); Schär (2020); Zhang *et al.* (2018).

Figure 4 shows how AMM can change C&S beyond recognition.

Strictly speaking, AMMs and decentralized exchanges are not dFMIs. They are decentralized applications ("dapps") which sit atop a blockchain, such as Ethereum. AMMs are non-custodial and provide atomic swap

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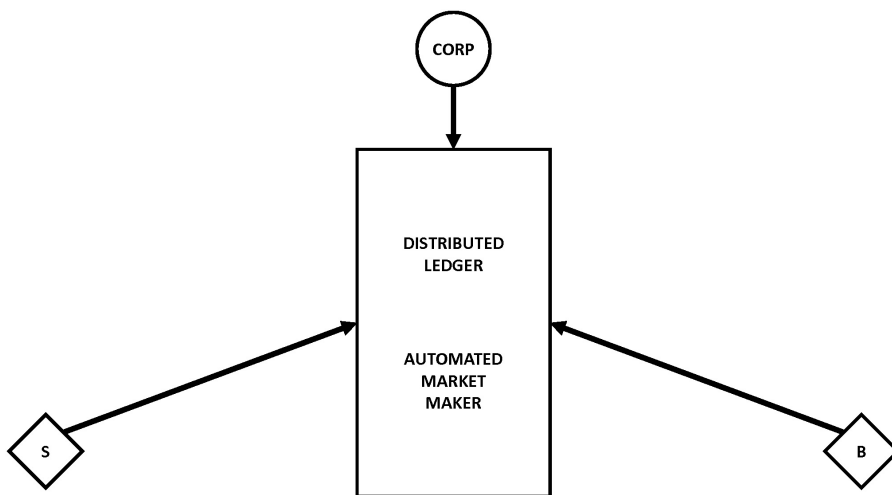[32] Examples of AMMs include Uniswap, Curve, and Balancer.

Fig. 4.   By using AMMs, one can eliminate the need for CCPs in the first place.

clearing which act as a helpful illustration for certain utilities we believe dFMIs could enable in the future. With a couple of caveats, a closer example of a candidate dFMI would be the Ethereum network itself, specifically the miners. Miners (or stakers) are the only participants who process transactions which are canonically included into blocks. This administrative block making process is important as without transactions sealed into blocks, there would be no blockchain.[33] Hypothetically, if Ethereum — or other popular blockchains — eventually secured and managed systemically important-sized values, then it could potentially be categorized as an FMI by regulators.[34]

3.12. *Recent experiments*

Without endorsing a specific effort, since 2016 there have been over 100 blockchain-based infrastructure proofs-of-concepts involving financial intermediaries. Many of the most recent ones involve wholesale CBDC experiments that are broken up into multiple phases with a variety of third-party vendors and labs in supporting roles.

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[33]Miners (specifically, mining pools) in Bitcoin and Ethereum can and do manually include transactions. Under some regulatory frameworks, this could be categorized as acting as an "administrator."

[34]In addition to clearing (but not necessarily settling) payment-related transactions, blockchains such as Ethereum can provide some of the functions that existing FMIs do, albeit in a manner that does not provide the level of surveillance-sharing requirements that regulators require.

The purpose of these experiments is manifold but often involve proving the feasibility of using "near-live" systems to settle digital assets on a distributed ledger with central bank money. Around a dozen have performed joint proof-of-concept experiments integrating tokenized digital assets and central bank money. As of this writing, a couple have been nominally turned-on in production and are believed to have resolved some of the technological and legal practicalities of transferring digital assets through (A) a wholesale CBDC issued onto a distributed digital asset platform; (B) linking the digital asset platform to the existing wholesale payment system. For instance, Project Helvetia has experimented the settlement of tokenized assets using central bank money, by means of collaboration between the BIS Innovation Hub, the Swiss National Bank, and the digital asset trading platform SIX (2020).

Yet in all instances, blockchain-based systems are still constrained and limited by existing systems they must connect to. In addition, single points of trust and single points of failure have been reintroduced. For instance, in Project Stella — a joint effort between the Bank of Japan and the European Central Bank — one takeaway was that certain distributed ledger architectures purposefully utilize a single validator for specific tasks, thus introducing single point of failure risks for the network and making them unfit for the purpose of a FMI; see ECB and BoJ (2020). Despite casting a wide net in discussing with vendors involved with both commercial bank and central bank projects, none are considered FMI at the time of this writing.[35]

While a wholesale CBDC is marketed as having when settling digital assets, it does raise significant policy and governance complications. Using existing systems with new Distributed Ledger Technology platforms may avoid some of these complications but, not surprisingly, misses considerable benefits of a fully decentralized, resilient network. Furthermore, several of the "stablecoin" related projects that have been launched for retail-focused uses ultimately rely on reusing commercial bank money, not central bank money which is what the PFMIs recommend.[36] Thus we feel that using narrow banks, instead of commercial banks, is a necessary ingredient in any

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[35] Almost all of the experimental systems remain relatively immature and fragile. Often the business model requires introducing a central party due to the usage of proprietary software licenses. Thus, the implementation compromises eat away at the promise of blockchain. As of this writing, none of the systems that have been launched in production are deemed systemic enough for them to be PFMI subjects.

[36] Principle 9: An FMI should conduct its money settlements in central bank money where practical and available. If central bank money is not used, an FMI should minimize and strictly control the credit and liquidity risk arising from the use of commercial bank money; see BIS (2012).

successful real-life implementation of the idea; see, e.g., Lipton *et al.* (2018); Levine (2019).

4. Conclusion

The central thesis of this paper is that financial services mechanisms and governance structures have not kept pace with the evolution of computing, and thus fail to capitalize on important risk reducing opportunities in the globally connected financial ecosystem where we operate today.

From trading to clearing and settlement, financial market infrastructures and their participants are central to the operation of our markets. With the introduction of technologies to financial services, the market started operating on relatively siloed market infrastructures, in a world perceived as completely connected from the user's perspective. This became a top concern for regulators and policy makers after the financial crisis of 2008. The call for transparency and better risk management brought the need for connectedness across market structures, both horizontally and vertically across the value chain. The available technology, access and governance paradigms have poised significant challenges and unveiled a range of misaligned incentives resulting from the increased intermediation.

Meanwhile, the demands of end users of our markets started to evolve. New areas of differentiation furthered innovations for financial services, including the distribution of new products, speed, transparency, choice and on-demand capabilities. These digital capabilities emerged as vital to address increasing customer demands. In addition to meeting these requirements, core infrastructure needed to comply with regulatory requirements and standards such as the PFMIs. The dFMI concept is a proposed path to address the challenges of our market structure today, as we build the future of product development and distribution in financial markets.

Significant amount of work is still required in order to begin implementing dFMIs. This can imply the transformation of existing infrastructures, as well as the emergence of new ones. As building blocks of this paradigm, the recent and most well-known initiative includes the Utility Settlement Coin initiative, which is now being developed by a consortium backed entity. The list of additional proposed initiatives is long and involves changes in business models, such as supporting trading of listed and OTC instruments from a single inventory.

Moreover, broader trends such as tokenization should be considered as an opportunity to build the next generation of dFMIs. In the realm of asset

tokenization, liquidity constraints are an important consideration. Initially, tokenized assets may not be traded as expected or as required in order to maintain adequate volumes to sustain market efficiency and price discovery. This could pose significant implications on trade execution, where low and fragmented levels of demand may hinder proper C&S functions. A proper legal and regulatory framework to support should incentivize adoption and liquidity, so as to promote the development of tokenized assets to run on dFMI platforms.

With tokens becoming adequate legal representatives of their underlying assets and value, this could present a sensible legal proposition to support a decentralized infrastructure. This should provide the ability to move in and out of contracts legally and efficiently. In the absence of intermediary fees, trades in tokenized assets can be more cost effective than in FMI structures, which would further support liquidity levels once the right network effects are achieved. In addition to cost savings, the higher transparency, efficiency of trades, anonymity and security are all attributes of a dFMI that would eventually support liquidity levels. Practical examples of this construct of tokens being traded on dFMIs take the form of digital assets, including tokenized securities and cash. On an economic level, markets should initially tokenize assets where the benefits above present a clear advantage for trading financial instruments in existence today. These should also be financial instruments for which there is a strong demand. On a technical level, it is important to determine the right blockchain structure, with the right economic incentives in place, to sustain an adequate market dynamic for a tokenized asset. These factors could ultimately determine the use cases for which tokenized assets acquire adoption, the possibility of scaling and ultimately incentivize liquidity overall across dFMI. As our markets move from dematerialized to digital assets, the markets supporting these instruments started getting organized with decentralized attributes. The upstream product and operational efficiency of tokenized cash or peer-to-peer cash initiatives will facilitate a range of decentralized functionality. We contend that peer-to-peer cash must incorporate global state otherwise the network is bifurcated with single-points-of-trust maintaining control of key infrastructure. This is a systemic risk and should be avoided. Several organizations have attempted to re-intermediate the network through business models involving licenses to these key pieces of infrastructure. This is a step backwards and historically results in vendor lock-in and specifically, the Hold Up Problem; see also BIS (2019). Yet challenges remain in tying a new and more

resilient infrastructure with business models that do not reintroduce intermediation through single-points-of-trust.

Concepts outlined in this paper have begun moving from theoretical stages to a practical application. As a whole, market participants have the opportunity to innovate around key function and decentralize some of the functionality as relevant, while addressing some of the challenges of the FMIs outlined in this paper.

Acknowledgments

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