Systemic Risk and Blockchain Technology

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After the crisis in 2008, blockchain and systemic risk have seen increasing interest. In this thesis I advocate for more research to be conducted on the two topics jointly after noticing a gap in the literature regarding the effects that using a blockchain based financial system could have on systemic risk. The thesis is an attempt to set the stage for future research, by describing the major sources of systemic risk, the most important characteristics of blockchain, and finally suggesting some topics for future research on systemic risk and blockchain in areas where blockchain could have the biggest impact.

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Abstract

After the crisis in 2008, blockchain and systemic risk have seen increasing interest. In this thesis I advocate for more research to be conducted on the two topics jointly after noticing a gap in the literature regarding the effects that using a blockchain based financial system could have on systemic risk. The thesis is an attempt to set the stage for future research, by describing the major sources of systemic risk, the most important characteristics of blockchain, and finally suggesting some topics for future research on systemic risk and blockchain in areas where blockchain could have the biggest impact.

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Chapter One: Introduction

Blockchain technology has been rapidly evolving after the invention of Bitcoin in 2008. Although in its most basic form it is a technology for recording transactions among users, its most advanced applications allow it to bring improvements to many sectors of the economy. Some of the industries in which blockchain has shown great potential are logistics, healthcare, and finance. In logistics, blockchain allows for the tracing of information about products throughout the supply chain. In healthcare, it has been used to securely keep track of patients' records. Lastly, in finance, it is showing promise when it comes to making transactions more secure and detecting or preventing fraud.

The advantages that this technology can bring make it likely that it will be widely used in the future, which brings us to the scope of this thesis: will the implementation of blockchain technology in the financial market increase systemic risk, or do its characteristics have the potential to reduce it? To address this question, I will determine which sources of systemic risk are the most relevant by looking at the academic literature, and address some of the measures that currently exist. Secondarily, I will address the technology by describing its main characteristics and the revolutionary features that make it different from other technologies. Lastly, I will combine the information gathered from the literature on systemic risk and the literature on blockchain technology and evidence the features that could help reduce systemic risk or the characteristics that might increase it.

Unfortunately, due to the newness of this technology there has been little research done specifically relating systemic risk and the technology. I suspect this might also be caused by the little knowledge there is about the technology, but also may be caused by some misconceptions about the technology that stop economists from separating blockchain technology from the reality of cryptocurrencies which have been associated with frauds in many occasions. For example, some scholars have addressed the discussion by using currently existing blockchains as proxies (see Schär 2021, Surujnath 2017), while others have discussed systemic risk in the context of cryptocurrencies and already existing blockchains. I believe that the use of private or consortium blockchains would be more appropriate if we were to use this technology to reshape the structure of the financial system, this is because a private blockchain would retain most of the characteristics and benefits of public blockchains, but also remove some of the systemic concerns that public blockchains bring. Private or consortium blockchains would also bring the least impactful change in terms of financial market structure, since this type of blockchain would only change the way transactions are recorded and processed, but it would not necessarily change who records the transactions.

This thesis will be divided in four chapters. The first one is a review of the literature on systemic risk sources and measures, covering the systemic risk taking behaviors of financial institutions, the contagion effects that happen after a systemic event and which cause the crisis to become systemic, and the amplification mechanisms that cause small problems to become bigger. The second chapter will be describing blockchain technology and its most important features which include decentralization, transparency, and encryption. In the second chapter I will also address cryptocurrencies. These first two chapters will serve as a foundation for the following two chapters which will address systemic risk in crypto markets and systemic risk in a blockchain based financial system. When it comes to systemic risk within crypto markets there seems to be no evidence that cryptocurrencies have the ability to reduce systemic risk, yet they seem to be increasing it and might pose threats to traditional markets if the two were to become more connected. Chapter four will discuss potential systemic risk reduction in a blockchain based financial system, the reductions would mostly come from the transparency and programmability that blockchain offers. The last chapter will conclude and discuss the findings.

Changing the structure of the financial system would certainly be a challenging task, there are several factors that would need to be considered when implementing a blockchain based financial system. Firstly, one must consider the role of the financial system, which is to efficiently distribute capital where it is needed, to achieve this goal, the financial system today uses intermediaries such as banks to provide credit to institutions and individuals that are the most likely to be able to repay the credit with interest. This process ensures that little to no capital goes unused and ensures that the projects yielding the highest expected returns are the ones that receive credit, promoting the growth of the economy. This role, which today is mostly played by banks and financial institutions could be revolutionized by a change in the structure of the financial system since blockchain could allow for peer-to-peer connections between individuals or firms looking for credit and investors looking to invest their money. Such a change would not only affect financial institutions, but also investors and firms. It is for this reason that research is important to understand which stakeholders might be the most affected by the changes, and how they should adapt. It is important therefore that the changes happen gradually and with pilot projects that run with small risks to give time to regulators to spot potential unforeseen challenges and address them in a safer setting. The slow approach to this change would also allow financial institutions and other stakeholders to start exploring the capabilities of a blockchain based financial system, allowing them to adapt to the changes as they are implemented. With the implementation of such pilot projects there would also be more information to determine if a blockchain based financial system is a viable option or not.

Chapter Two: Systemic Risk

The economic literature has yet to agree on a single definition of what systemic risk is, in this chapter I will attempt to address the different definitions of systemic risk that can be found in the literature and the different methods used to evaluate the level of systemic risk in an economy. Systemic risk is sometimes defined using the consequences of it, these can be panics, bank runs, failures of entire firms or markets that are interconnected. Other times, systemic risk is defined by the potential causes, these can be "too big to fail" corporations, too interconnected markets, or excessive leverage (Surujnath 2017). The literature is also divided in two when it comes to deciding how to deal with systemic risk. On one side there are scholars attempting to determine the major sources of systemic risk and addressing the single sources directly, on the other side there are more comprehensive measures that aim at evaluating the level of systemic risk in the economy and potentially implementing a tax to maintain an optimal level of risk in the economy (Benoit et al. 2017). For the purpose of this thesis, systemic risk should be seen as the risk that the failure of one institution or group of institutions causes a domino effect that collapses the entire economy.

The chapter will be divided into two parts. The first part will focus on the sources of systemic risk as described by Benoit et al. (2017), these are systemic risk taking, contagion between financial institutions, and amplification mechanisms. In the second part of this chapter, I will discuss how systemic risk is being measured by addressing the regulatory approach, the measures of systemic risk sources, and global measures of systemic risk.

Sources of Systemic Risk

There are several sources of systemic risk, and that is probably why it is difficult for the literature to agree on a single definition, nonetheless Benoit et al. (2017) divides them into three categories. Systemic risk taking includes all those risks that are directly affected by banks' activities; contagion is the risk of losses to spillover to other financial institutions; lastly, there are some amplification mechanisms that can enlarge systemic risks. Amplification mechanisms are a consequence of risk-taking behaviors and they are responsible for turning small shocks into large scale crises, in this thesis I will discuss them when discussing the risk taking behaviors that are the source of such amplification mechanisms.

Systemic Risk Taking

We can see systemic risk taking as the first step to a systemic crisis, the setup of risks that lay a foundation for systemic crises to form. In this step banks and other financial institutions are taking risks that make the system more fragile. Minsky had identified this risk-taking behavior as a trend in the economy, in his financial instability hypothesis he claimed that firms have a natural tendency to become speculative and eventually Ponzi over time (Minsky 1978). The cycle starts after a crisis has occurred, in those times borrowers and lenders are more cautious, firms borrowing capital are hedgers, meaning that their expected profits are enough to repay their debt commitments. As time progresses, a precedent is formed not only for lenders that can observe good behavior from borrowers who are capable of repaying their debts, but also from the perspective of borrowers who see that their profit expectations are being met, this not only changes the sentiment of lenders and borrowers, but also affects the statistical measures of risk and since the standard deviation of returns has gotten smaller the cushion of safety will be reduced (Kregel 2012). Firms become speculative and are now only able to repay the interest rates on their debt in the short run, but they expect to increase their profits in the long run and be able to repay the debt. Overall, the market becomes fragile over time, making it possible for a small shock or even a slowdown in the economy to have a big impact and potentially cause a financial crisis. In this section we will see what elements can make the market fragile and lay the foundation for a systemic crisis to unfold.

Correlated Investments

It is obvious that if financial institutions invest in the same assets, then they will have the same type of risks, therefore when one fails, all the others fail as well. Therefore, correlation between financial institutions and between their investments is one of the most important sources of systemic risk in the economy. For this reason, correlation has been proposed by several authors as an indicator of systemic risk (see for example Lehar 2005, Brownlees and Engle 2012, Cai et al. 2018).

There are several factors that can affect the correlation of financial investments between institutions. Acharya (2009) finds that in the presence of a negative externality of one bank's failure, other banks will tend to look for safer investments, making their investments correlated. Another reason for correlated investment behavior from banks and financial institutions is banks' expectation of government bailouts, Acharya and

Yorulmazer (2008) explain that a collective failure in the financial system would more likely incentivize the government to bail out banks, while when a single bank fails, the government has a lower incentive to bail it out, therefore it is better for banks to correlate their investments and fail together rather than to fail alone. In the article, the authors use the expression too-many-to-fail to describe this situation. The problem of too-many-to-fail institutions has been more recently studied by Kress and Turk (2020) who claim that the current regulation has been too focused on too-big-to-fail institutions, neglecting the fact that banking crises historically happened when several institutions failed at the same time, on the other hand Shimizu and Ly (2017) noticed that regulation aimed at providing massive bailouts increased the tendency of institutions to partake in herd behavior, therefore suggesting regulation more focused on a smaller number of systemically important institutions.

Lastly, another topic in the literature that can be associated with correlation is the topic of diversification. If each agent was able to perfectly diversify their portfolio, then their portfolio would be representative of the economy, and all agents would therefore have the same risk (in other words they would be all perfectly correlated). Battiston et al. (2012) find that after a certain level of diversification, the benefits are counterbalanced by the higher chance of incurring in credit runs if the agents have many counterparties. In other words, they argue that increasing diversification brings lower individual risks, but at the same time it brings higher systemic risk.

Too-Big-to-Fail and Too-Interconnected-to-Fail

The second source of systemic risk that has been deeply studied in the literature is the existence of systemically important institutions whose failure would result in widespread failures throughout the economy. These institutions are usually referred to as too-big-to-fail institutions, although many scholars extend the definition to include banks that are not necessarily large in size but perform crucial tasks for the smooth functioning of the economy. Moreover, there is the idea of too-interconnected-to-fail that plays a role in the discussion since financial institutions are capable of taking leverage, because of their interconnectedness, they might become systemically important although their assets are relatively small in size. Another point to make is that the size of a non-interconnected institution does not matter much as it will not have any impact on others. This factor has been recently evidenced by the crypto market crash that saw a loss of about 2 trillion dollars in value (CoinMarketCap 2023) but had no significant effect on other markets due to its low interconnectedness (Aquilina et al. 2023). For these reasons, too-big-to-fail (TBTF) will from now mean “systemically important”.

The notion TBTF is the idea that an institution becomes so large or so interconnected (or both) to the point that its failure would be likely to cause issues for the economy, potentially a systemic crisis. This is mostly an issue for financial corporations due to their central role in the economy, but it is not limited to it. Green et al. (2010) extends the definition of TBTF to any company that the government would be willing to risk taxpayers’ money to save rather than incur the costs associated with its bankruptcy, therefore including corporations external to the financial sector such as airline companies that the government would be willing to bailout, or large car manufacturers. In general, a TBTF corporation is one that the government would be willing to save because it is believed critical to the economy. The consequences of its failure are estimated to be more costly than the bailout price. Ennis and Malek (2005) spot a potential issue in this regulatory behavior, they say that if market participants believed that the government would be willing to bailout TBTF corporations, then this would give an incentive for corporations to become TBTF, therefore taking more risky position that threaten the economy. This issue is also highlighted by Labonte (2014) who views policies protecting creditors and counterparties of TBTF corporations a source of moral hazard causing market participants to be less incentivized to hedge against extreme outcomes.

Liquidity Risk

Another source of systemic risk is the lack of liquidity in the economy. Logically, if banks hold illiquid assets, they are more likely to sell at a discount if they ever need liquidity, thus creating the basis for a crash in prices when a liquidity shortage occurs. For example, if all banks have illiquid assets, and for any reason creditors ask for their money in return, banks will be forced to sell their assets in order to provide creditors with the liquidity they request. Seeking liquidity, banks will be forced to sell their assets at a discount due to the illiquid nature of them, driving the prices of those assets down, which may cause panics or runs and eventually a domino effect of falling prices. Brunnermeier and Pedersen (2009) explain that liquidity, in the market, is affected by traders' willingness to buy/sell a certain asset, but also that their willingness to trade a certain asset is affected by their availability of funding, in some cases, the trader's availability of funding will depend on the liquidity of certain assets, leading to a liquidity spiral where the lack of liquidity leads to a lack of funding, which further reduces liquidity.

When it comes to banks and other financial institutions, the two factors that can affect their liquidity risk are their assets and their liabilities. The liquidity risk will be higher, not only if the assets held by the institution are less liquid, but it may also be increased by short-term liabilities since they may force the institutions to sell their assets in search for capital to repay their creditors or debt obligations. On this note, Pierret (2015) finds that higher levels of liquidity can help institutions in times of need by allowing them to remain solvent, which helps them to retain their access to short-term funding, the access to this source of funding would be lost if markets believed the bank to be insolvent. This analysis would suggest that to fulfill their liquidity requirements, banks can use short-term debt. A similar analysis is performed in Cao and Illing (2010) who find that banks have an incentive to invest in illiquid long-term projects that generate relatively high returns, and then borrow liquidity from prudent banks since the interests will be covered by the gains of the high yielding long-term investments.

The lack of liquidity in the market is also the cause or consequence of amplification mechanisms, according to Benoit et al. (2017) there are three types of amplification mechanisms, these are liquidity-driven crises, market freezes, and coordination failures and runs. All three of them are strictly related to liquidity issues in the market. In the next few paragraphs, I will describe them in more detail.

Liquidity-Driven Crises

In Allen and Gale (2004) we find that small liquidity shocks are always associated with large fluctuations in asset prices. The importance of liquidity has been already addressed as a source of systemic risk for the economy, but it can also become an amplifier of shocks. The reasoning is that, if the market is not liquid, when there is a drop in prices, the collateral constraints of financial intermediaries will force them to liquidate their assets at a discount. By doing so, the prices will be pushed down, escalating the small shock to a significant fluctuation in prices creating a feedback loop that will not stop on its own. This event has been called a liquidity spiral (see for example Brunnermeier and Ohekme 2013a, Brunnermeier and Cheridito 2019, Pedersen 2008). Brunnermeier and Oehmke (2013a) evidence this possibility by saying that if a bank were to do a "fire-sale liquidation" of its assets it may drive down the value of another bank's portfolio, leading this second bank to do the same and so on. More recently, Brunnermeier and Cheridito (2019) say that liquidity spirals can amplify contagion and common exposures worsening the crisis. Korinek (2011) finds that the amplification effect of liquidity leads financial firms to undervalue liquidity during crises, for example it leads them to disregard the negative externalities that the fire sale of their assets can have on other institutions.

Market Freezes

The next amplification mechanism is market freezes, which can be seen as an extreme form of illiquidity (Benoit et al. 2017). Market freezes amplify shocks in a similar way to liquidity, just at the extreme. Therefore, the analysis of market freezes is focused on finding ways to avoid them, the literature focuses mainly on information issues, these can be lack of information or also informational asymmetries in the market. In Gorton and Ordonez (2014) the lack of information is intrinsic to the debt creator's tendency to avoid incurring the costs of collecting information about the borrower. This, according to their study, leads to a situation in which all collateral looks alike, making it impossible to distinguish between good and bad collateral and eventually allowing firms with bad collateral to access credit making the economy more fragile. Another perspective is presented by Caballero and Simsek (2013) who show how a complex system of interlinkages can create uncertainty among members. In their analysis, members of the system are able to see their direct links but are unable to assess counterparty risks coming from indirect sources. For example, if bank A is linked to bank B, and bank B is also linked to bank C, a failure of bank C will have an impact on bank B and indirectly also on bank A, yet bank A will have difficulties assessing its counterparty risk due to the indirect nature of its link to bank C. Caballero and Simsek (2013) say that due to this complexity and uncertainty there is potential for fire sales and freezes to arise even from small shocks. Acharya et al. (2011) suggest that market freezes can also be modeled by using the notion of Knightian uncertainty (Knight 1921). The lack of knowledge about the counterparty risks associated to a shock in the economy might lead agents to liquidate their positions and hoard liquidity, causing a market freeze. This idea is also supported by the findings of Heider et al. (2015) who show that liquidity hoarding and counterparty risk are intrinsically linked, the reasoning behind it is that banks will decide to hoard liquidity if the asymmetric information induces them to expect an interbank market malfunctioning.

Coordination Failures

Coordination failures and runs are another amplification mechanism that can arise from imperfect information and/or fear of a market crisis. Instead of being fueled by illiquidity, this type of amplification mechanism causes illiquidity in the market because it dries institutions of the capital they need to perform their regular activities. Differently from market freezes, these are started by creditors rather than banks. Jackson and Pernoud (2021) explain that the risk is associated with the nature of banks, since banks provide long-term illiquid financing for investments using short-term liquid deposits, they are vulnerable to the possibility that depositors decide to withdraw their money before the bank has been able to realize its investments. If many of them withdraw their funds at the same time it could force the bank into default. This risk is not necessarily triggered by a bank's fundamentals, but it can also be caused by the expectation of depositors that the bank might fail (Jackson and Pernoud 2021). Kaufman (2008) claims that bank runs are less likely today thanks to the introduction of deposit insurances, on the other hand, this observation is only valid in relation to traditional banks, shadow banking could still face runs since it lacks access to the deposit insurances that make bank runs less likely. Moreover, there have been literature assessing the new idea of financial market runs (see for example Bernardo and Welch 2002 and 2004, Wagner 2013). Financial market runs occur when investors choose to liquidate their investments fearing that others will do the same. The expectation of investors that others will sell and drive prices lower moves them to start selling in advance causing a financial market run were prices drop significantly. Although I am discussing this amplification mechanism in the context of liquidity, it should be kept in mind that it has to do with issues in network structure and information, whether this is asymmetric information or the lack of it.

Tail Risk

As mentioned in Benoit et al. (2017), for systemic risk events to happen, not only do risk exposures need to be correlated, but they also need to be large enough. Although a bank's own risk does not necessarily imply higher levels of systemic risk, there is a type of risk that can be easily underestimated leading to higher levels of contagion in the case of extreme events, this risk is referred to as tail risk.

Nair and Kayal (2022) say that tail-risk is used to refer to a move of three or more standard deviations in the probability distribution of returns. In other words, if we put the expected returns on a bell curve, tail-risk would happen when the realized returns were three or more standard deviations away from the mean. Although extreme events may occur in both ways, meaning that the returns could be higher or lower by three standard deviations, usually when talking about tail risk, the biggest concern is for returns that are lower than the expectation. In the case of such an event happening, the losses may spillover if the hedging was not performed accurately.

According to Perotti et al. (2011), banks never internalize the negative realizations of tail risk projects. Moreover, they add that larger banks may be incentivized to take higher risks. In their article, they explain that tail risk leads to insolvency independently of the initial bank's capital. In addition, the higher capital gives banks more room for risk taking while maintaining their capital ratio requirements in the event of minor losses. All these factors combined allow larger financial institutions to take riskier positions. Another big factor affecting tail risks is shadow banking, shadow banking is a term used to describe those institutions that engage in practices similar to those of banks, such as using deposits to engage in credit, maturity, and liquidity transformation, but do so without the regulation or reserve requirements of government agencies, they therefore are more fragile due to their lack of the sources of liquidity and insurance provided by the Federal Reserve's discount window and Federal Deposit Insurance Corporation (FDIC) (Adrian and Ashcraft 2016). Gennaioli et al. (2013) show how the shadow banking system is vulnerable to crises when investors neglect tail risk, this happens because securitization allows for higher risk-taking. One reason why this might happen is the tendency for investors to misperceive risk. Also, Thieman and Troger (2020) evidence the need for supervision on financial innovation aimed at avoiding prudential regulation to gain insight about the potential tail risks posed by the new financial instruments.

Tail risks have also been utilized by Hardle et al (2016) to develop a widely used method of assessing systemic risk called TENET (tail-event driven NETwork risk). We will discuss measures of systemic risk further in this chapter.

Contagion

In the talk about systemic risk a central topic is contagion. Contagion has been deeply studied in the literature. Silva et al. (2017), who performed a review of the literature on systemic risk find that out of the 266 articles they studied approximately 55 addressed contagion, making it the second most researched topic in the literature. Benoit et al. (2017) define three different ways in which contagion could occur which are (1) balance sheet contagion, (2) payment and clearing infrastructures, and (3) informational contagion.

Balance sheet contagion involves the links between assets and liabilities held by banks. For example, when a bank's liabilities are assets from other banks, this could cause contagion if the bank holding the liabilities were to default, potentially causing a domino effect. An important contribution regarding financial contagion was brought by Allen and Gale (2000), they determined that financial contagion happens through the interconnections within the financial market, therefore, even if the individual bank is fully diversified, a liquidity shock could still spread through the linkages of the bank within the financial sector. Allen and Gale (2000) suggest that only when the network is complete, meaning that assets and liabilities held by other banks are evenly distributed, the level of systemic risk is reduced. This theory has been challenged by Battiston et al.

(2012) who found that complete networks are not necessarily better at reducing systemic risk. They find that in the presence of amplification mechanisms, the linkages may allow for the propagation of contagion throughout the system, thus increasing the level of systemic risk. On a similar tone, Anderson et al. (2019) find that higher linkages increase systemic risk in the presence of large shocks in highly interconnected center banks.

Payment and clearing infrastructures as a source of contagion relates to anything that deals with the methods banks and other financial institutions use to exchange capital including norms that can be peculiar to individual banks, but also central counterparties (CCP) that manage the clearing of transactions. CCPs have been addressed by many articles as a source of systemic risk due to their central role in the financial system. Amini et al. (2015) find that although CCPs allow a reduction in bank's liquidation and shortfall losses, they do not always reduce systemic risk. They propose a CCP fee and guarantee fund to reduce systemic risk. Avgouelas and Kiayias (2019) evidence the systemic importance of CCPs when it comes to over-the-counter (OTC) transactions. They say that OTC transactions increase counterparty risks, and the centralization of them to be cleared by CCPs has been promoted after the 2008 crisis. At the same time, the concentration of OTC markets in CCPs gives rise to concerns for systemic risk if a CCP were to fail. They continue their discussion by promoting DLT technology as a potential solution to this problem, but we will discuss this in a later chapter.

The last type of contagion evidenced by Benoit et al. (2017) is informational contagion. This has to do with any potential informational asymmetry in the financial system. To give an example, if an institution were to default, the uncertainty about the financial stability of other institutions might cause investors to run to withdraw their capital, weakening the other bank and starting a domino effect that can cause systemic failures. For example, Vaugirard (2007) says that in the presence of incomplete information, a crisis may cause investors to lose confidence. In a more recent study, Raffestin (2021) says that an important factor affecting informational contagion is parameter uncertainty, in other words, when depositors in a bank lack knowledge of the conditions of their bank, they will be more susceptible to negative news about other banks, making potential runs more likely. Trevino (2020) adds to the discussion that agents treat information differently depending on its origin, and that they usually overreact to public information about social behavior. This tendency to overreact could lead to increases in contagion.

Measures of systemic risk

In this section of the chapter, I will discuss some global measures of systemic risk that can be found in the literature, trying to address their strengths and weaknesses. The most common measures try to either estimate the value at risk (VaR) or the expected shortfall (ES) to assess systemic risk and do so by using institution specific information or macroeconomic information that represent the general state of the economy. I will discuss ΔCoVaR, systemic expected shortfall (SES) and marginal expected shortfall (MES), SRISK, TENET, and the more recent SystRisk. I decided to focus on these measures because they are widely used in the literature by looking at the number of citations (for example ΔCoVaR and SES and MES have over three thousand citations), except for SystRisk which I am including since it is a more recent measure proposed by Brunnermeier, who coauthored the article on ΔCoVaR.

ΔCoVaR was proposed by Adrian and Brunermeier (2016) and is a measure that tries to assess the tail-dependency between an institution and the entire financial system. The goal of ΔCoVaR is to assess the VaR (value at risk) of the entire financial system conditional (from here the "Co" in the name) on a single institution being in a particular state. In other words, it tries to determine what risk the entire system is facing when a specific entity is in a specific state, for a real-life example, today it could be used to determine the VaR of the financial system due to the failure of SVB, or to the specific state in which other banks are right now. To estimate the level of systemic risk, this measure uses firm specific characteristics such as size, leverage, and maturity mismatch, but also global measures such as asset price booms, market volatility, and fixed income spreads. Adrian and Brunermeier (2016) also developed a forward- ΔCoVaR to predict future ΔCoVaR, this model uses lagged variables and when tested for its forecasting capabilities, and according to Adrian and Brunnermeier (2016) was able to predict over one third of the future ΔCoVaR.

Acharya et al. (2017) developed the measures of SES and MES basing themselves on the assumption that undercapitalization in the economy is responsible for increases in systemic risk. The model looks at the worst 5% days in terms of market outcomes and uses this results to determine the MES, it then uses the MES to assess the SES which is an estimate of what would happen in case of a crisis. Since when a firm increases the level of systemic risk, the cost is shared by all firms in the economy, Acharya et al. (2017) wanted to design this measure so that regulators could use it to impose a "systemic tax" that was based on the systemic risk contributions of individual firms which would reduce the incentive of firms to engage in activities that increase the level of systemic risk. This measure differs from the measure proposed by Adrian and Brunnermeier (2016) because SES and MES attempt to determine a financial firm's stress conditional on systemic stress rather than conditional on the stress of another firm. Acharya et al. (2017) also say that their proposed measure has the advantage to consider losses beyond the VaR (Value at Risk) threshold of the ΔCoVaR measure.

Another popular measure is SRISK, it was proposed by Brownlees and Engle (2016) and, similarly to the previous ones, it measures the systemic risk contribution of financial firms. Brownlees and Engle developed this measure expanding on the MES measure. Differently from MES, SRISK also accounts for the liabilities and the size of the institution contributing to systemic risk (Benoit et al. 2017). The authors find that this measure is capable of predicting increases in unemployment and declines in industrial production but performs best over longer horizons. A feature of this model is that it is constructed using publicly available information, this ensures its wide applicability and low cost.

Hardle et al. (2016) used a different approach to assessing systemic risk. In their model called TENET, they are able to distinguish between emitters and receivers of systemic risk in a network of institutions. To construct this measure, they firstly estimate tail events for each institution in the network using VaR, then they assess the interconnections within the network, lastly they identify the systemic risk contributors. This model can be used to address the overall systemic risk, but it can also point out the largest risk emitters and receivers which, according to the authors, are both systemically important. Overall, regulators could use the analysis provided by this measure to identify the biggest players and address them directly.

The last measure I will discuss is SystRisk (Brunnermeier and Cheredito 2019). SystRisk provides insight for regulators about the a priori cost of the negative externality that would be generated by the failure of a financial institution. The measure could be used to set up some type of insurance or tax that financial institutions have to pay in relation to their contributions to systemic risk, it also allows regulators to know how much they should be willing to spend to bail out a failing institution basing themselves on the cost of the negative externality in case of failure. The improvement Brunnermeier and Cheredito (2019) bring to the discussion of systemic risk is their consideration of leverage and liquidity mismatch, this allows their model to find systemic fragility even in times of booms or low volatility, generating the potential for more preemptive regulation rather than regulation that tries to reduce systemic risk when there are downturns in the economy. Lastly, the authors propose three regulatory actions that could be used, the first is to set systemic risk limits, imposing systemic risk taxes, and setting up a cap and trade system. Risk limits are the most imposing and would require regulators to decide what the optimal level of systemic risk is. A tax would allow the market to address the systemic risk on its own, but it would not give any incentive for institutions to reduce systemic risk, it would only discourage them from increasing it. Lastly, the cap and trade solution would work similarly to the trade schemes for pollution, giving institutions reducing the overall systemic risk a chance to sell their "systemic risk permits" to institutions that contributed excessively and profit from the sale.

Reflections

In this chapter we have reviewed the literature on systemic risk in traditional markets, addressing the sources of systemic risk and the measures that have been proposed in the literature that discusses systemic risk in traditional markets. There is a new strand of literature that tries to include blockchain and cryptocurrencies in the discussion about systemic risk, although the literature on this topic is still relatively new, and is significantly underdeveloped compared to the literature on traditional markets. One reason why the literature on systemic risk and blockchain/cryptocurrencies has not been explored more could be certainly the infancy of this new technology that has only gained interest since the crypto market boom in 2017, but it could also be due to the lack of understanding of this new technology and the confusion in associating the technology with cryptocurrencies. For these reasons, in the next chapter I will attempt to explain the main features and capabilities of blockchain technology, its uses beyond the currently existing blockchains, and explain what cryptocurrencies are.

Chapter Three: Blockchain Technology and Systemic Risk

To understand why blockchain technology could help us in our fight against systemic risk we should firstly understand what the technology is and how it works, starting with the distinction between blockchain and blockchain technology. When we talk about blockchain technology we are referring to a specific type of DLT (distributed ledger technology) that uses cryptography to secure transactions, while when we talk about blockchain we are referring to a single decentralized ledger which might have specific features, characteristics, and limitations. After having defined what blockchain technology is, I will use "DLT" and "blockchain technology interchangeably" due to their similarity. For the reader's reference, it should be known that in general DLT is used as an umbrella term that applies to all types of systems relying on a shared database that records, processes, and verifies transactions on an open network. On the other hand, blockchain technology is a specific type of DLT that uses cryptography to secure transactions (see Abrol 2022).

Describing Blockchain Technology

To have a good understanding of what a blockchain technology is we need to describe two characteristics of it: (1) the distributed ledger part which applies to all decentralized ledgers; and (2) the blockchain specific characteristics that allow for greater security. In the first part of this chapter I will define what blockchain technology is, I will explain some the unique characteristics it has, and I will talk about some different implementations of it.

As mentioned before, Blockchain technology is a specific type of DLT, therefore we can start by understanding what a DLT is. DLT has been defined in several different ways in the literature (Rauchs et al. 2018). The U.S. Government Accountability Office defines DLT as “a secure way of conducting and recording transfers of digital assets without the need for a central authority”, the World Bank (Natarajan et al. 2017) defined it as an “approach to recording and sharing data across multiple data stores (or ledgers)” also specifying that the “technology allows for transactions and data to be recorded, shared, and synchronized across a distributed network of different network participants”. Overall, DLT is a technology that allows users to store data across multiple nodes on a network. All nodes have an identical copy of the data implying that if a node were to become inactive for some reason, the data would still be retrievable from one of the other nodes, the network would fail only if every node were to fail. Blockchain technology is a specific application of DLT that uses cryptographic proof to record and update data. Data is recorded in blocks that are linked to one another like a chain, hence the name blockchain.

So, how does a blockchain function? To understand how blockchains work I will use as an example the Bitcoin blockchain since it is considered to be the first implementation of modern blockchain technology (Popovsky and Soussou 2018) and can serve to understand the general idea of how a blockchain works. Let us say that a new transaction happened on the blockchain, before the transaction is recorded it is shared to all the nodes present in the network (nodes are computers with an algorithm that verifies transactions and records data), the nodes will verify that the account sending Bitcoins actually has the Bitcoins it is trying to send. After the nodes have verified the validity of the transaction and have reached a consensus, the transaction is added to a block along with other transactions. Once the data limit for the block has been reached, the block is verified by all nodes in the network, when a consensus is reached it gets approved and then attached to the chain through a cryptographic process which links it to all previous blocks, ensuring that the past blocks cannot be altered anymore. In summary, each block contains transactions that are verified and shared among all the nodes in the network so that there is consistency among nodes, each block has a starting value and ending value that are shared with the previous and subsequent block respectively. Once the block has been added to the chain it locks each previous block from being modified. All network participants have access to the information present in the blockchain, allowing them to see all current and past transactions.

Unique Features of Blockchain Technology

Cost Reduction

The first blockchain application that gained traction to become widely used is the Bitcoin blockchain. Bitcoin was developed to allow peer-to-peer transactions without the need of trust (Nakamoto 2008). This brings us to one of the first features of blockchain technology, it allows for peer-to-peer payments that rely on cryptography instead of trust. Each blockchain might have a different cryptographic method of validation for the transactions, nonetheless, the need for third party interaction to validate transactions is removed and with it all the costs associated with third parties are removed as well.

Transactions on a blockchain could become less expensive while also being recorded faster than in traditional markets.

One example of how blockchain would be able to reduce transaction costs is in the stock market. According to Al-Jarodi and Mohamed (2019), blockchain technology has been used to develop platforms based on blockchain that reduce costs and time of settlement (for example see tZERO or Chain). Similarly, Ahluwalia et al. (2020) find that the use of blockchain technology would remove the need for intermediaries, thus facilitating transactions in the system and reducing the cost of transactions.

Catalini and Gans (2020) perform an analysis from an economic perspective, finding that blockchain can help reduce two types of costs. The first one is the cost of verification, meaning that a blockchain has the potential to replace third party intermediaries that verify the validity or authenticity of a good (or asset) by providing full traceability of transactions. The second cost reduction happens in network costs, these are the costs associated with starting a network and scaling it, once again the blockchain helps by removing intermediaries. Catalini and Gans (2020) also mention that the blockchain could be used to incentivize desired behaviors and provide the examples of ensuring sufficient resource availability in the network to meet demand, or even encourage spending or saving behavior, I will come back to this idea of using the blockchain technology to incentivize behavior when I will talk about the programmability of blockchains.

Informational Advantage/Transparency

The second important feature of blockchain is a product of its decentralized nature, since every node has access to the same type of data, it allows for information sharing with the potential to reduce information asymmetries. A blockchain based system has the potential to increase transparency among network participants (Avgouelas and Kiayias 2019), this feature could potentially reduce informational asymmetries in the market. This aspect of blockchain has been studied in the literature, especially for informational asymmetries in supply chain and logistics (see Malinova and Stark 2017, Longo et al. 2019, Liu et al. 2021 for example). Moreover, the use of blockchain can benefit financial accounting, according to Yu et al. (2018), on top of reducing informational asymmetries, blockchain can reduce errors in disclosures between firms and investors. This could improve investor's confidence about a firm's outlook and reduce the risk of panics due to uncertainty.

One important thing to mention is that the positive effects of blockchain on informational asymmetry and transparency can only exist within the network. For example, Ante (2020) finds that informational asymmetries still exist in the Bitcoin environment when traders have knowledge about large sales or purchases of Bitcoins are about to happen, in other words if investors have outside knowledge that cannot be captured by the blockchain, such as information about a large trader choosing to sell large sums of an asset, the informational asymmetry will continue existing. Every other player in the network can simply react as soon as the large trades take place and are recorded on the blockchain.

When it comes to potential threats related to transparency, we must consider concerns regarding privacy and the disclosure of investment strategies. These issues could be solved using a consortium blockchain and by disclosing only the information that ate necessary to reduce the informational asymmetries in the market.

Overall, blockchain has the potential to improve transparency and reduce informational asymmetries among market participants. The technology is already being used by logistic companies to solve informational challenges and could be used in financial markets as well.

Immutability

Another important feature of blockchains is the chain structure that allows past data to always remain immutable and retrievable. When a new block is added to the chain, it is linked to the previous one through an encrypted number called a hash, this system ensures that if someone wanted to change a previous block the link would be broken and the nodes in the network would recognize the malicious node and exclude it from the network, therefore maintaining the integrity of the data.

Once again, this feature of blockchain has been mostly studied in the context of supply chains to trace products along a supply chain. Sunny et al. (2020) say that most of the studies in this context propose the use of blockchain traceability to eliminate the creation of counterfeit products, monitor quality, and manage business processes. The immutability allows for easier traceability of all the transactions that have happened in the network. A study about agriculture traceability system shows how blockchain could be used, along with RFID tags that trace the physical location of the products, to ensure the safety and quality of foods while also reducing losses along the supply chain (Demestichas et al. 2020). The system could allow end customers to see the origin of the products they purchase.

A similar concept could be applied to financial markets. Here the immutability and traceability of transactions could allow investors to know where the loans, securities, or derivatives originated. For example, an investor wanting to invest in a mortgage backed security would be able to trace the origin of each mortgage present in the security and have a chance to reassess the risks associated with each specific mortgage.

Programmability

A more advanced feature of blockchain that exists for example in the Ethereum blockchain is programmability of tasks and functions. Since blockchains are virtual environments, it is possible to implement functions that allow for the automation of certain tasks. These functions are called smart contracts, although the term might be misleading since they are not contracts in the general conception used in the context of law. Smart contracts can be thought as functions that automatically enforce the contractual agreements between the user and the blockchain. To give an example, a smart contract might move a certain amount of funds from one account to the other when a certain deadline is reached, the transfer would happen automatically and without the need for any additional input from anyone. A weakness of smart contracts is that they cannot be modified, instead what programmers would not is create a new contract that nullifies the previous one and create a new one with the intended changes. In summary, the programmability of blockchains depends on smart contracts which allow them to have built-in functions that automatically execute functions when certain conditions are met. Thanks to this unique technology, blockchains have been able to accommodate many needs for different industries. An example of application that smart contracts would provide is in supply chain models, when a product has to go through a long shipping process, using blockchain technology, both the seller and buyer would be able to track every movement, then once the product reaches its final destination, a smart contract could be developed so that the funds from the buyer automatically get transferred to the seller. For the purpose of this thesis it is important to know that blockchain allows for this type of contracts to exist and the only limitations are in the programmer's ability to design a smart contract that perfectly reflects what the user desires. There could be a lot more to be said about blockchain programmability and smart contracts, but they would go beyond the scope of this thesis, for more information please refer to "Smart Contracts" by Kolvart et al. (2016), or "An overview on smart contracts: Challenges, advances and platforms" by Zheng et al. (2020).

Different Types of Blockchains

In this section I will explain the distinction between permissioned and permissionless blockchains and I will try to explain the benefits and drawbacks of the two types.

Permissionless blockchains allow users to become nodes freely, each node in a permissionless blockchain has equal rights and access to all the information available within the network. On the contrary, permissioned blockchains restrict access to the blockchain on top of restricting the rights of the nodes (Wegrzyn and Wang 2021). The difference between these two network structures lies in the security, transparency, and speed of transactions. Permissionless blockchains tend to have more nodes validating transactions and securing the integrity of the data, the free access to the network also allows virtually anyone to have access to the same information, yet the large number of nodes needed to validate transactions slows down the speed at which transactions can be validated. For this reason, permissionless blockchains are great for security and transparency, while permissioned blockchains allow for more privacy and speed of transactions.

To further expand our understanding of blockchains we can fit some examples of existing blockchains into these macro-categories. Permissionless blockchains can be represented by public blockchains, for example Bitcoin or Ethereum which are used mainly for cryptocurrencies (Wegrzyn and Wang 2021). The nodes in a public blockchain validate transactions and are rewarded with some cryptocurrency in return, this process is called mining. On the opposite end of the spectrum, we have private blockchains which only have a single entity who controls them, this type of blockchain can be used to transfer and trace assets, but also to automate processes (Guegan 2017). The central authority has the power to allow nodes and also the power to choose what rights each node has. Both public and private blockchains have drawbacks, public blockchains inherit the longer transaction period characteristic to permissionless blockchains, while private blockchains come with higher vulnerability to fraud or malicious intent from the central authority (Wegrzyn and Wang 2021).

To capture the potentials and reduce the drawbacks of public and private blockchains we can use consortium or hybrid solutions. A consortium blockchains is similar to a private one, but instead of having a single central authority, the central authority is comprised of a group of organizations. This allows for higher security, while maintaining higher transaction speeds. An example of consortium blockchain is Corda which was designed to allow financial institutions to interact with each other on a global financial network (Brown 2016). Lastly, hybrid blockchains are permissioned blockchains that have some permissionless features, for example a hybrid blockchain could retain permission for validating transactions and accessing certain information, keeping the speed and privacy of private blockchains, while also allowing permissionless access to data regarding transactions, achieving transparency similar to a public blockchain.

Cryptocurrencies

Cryptocurrencies are a type of digital currency also called digital coins. In the most simplistic view, cryptocurrencies are tokens specific to blockchains and are used to transact and exchange value on blockchains. For example, if I wanted to exchange value on the Bitcoin blockchain I could send some of my Bitcoins to another user and transfer value to them. Cryptocurrencies also serve as incentive for nodes to record transactions, in a process called mining, nodes are rewarded a certain quantity of cryptocurrencies for recording transactions, the reward might be in the form of new coins being created (e.g. the Bitcoin blockchain), or in the form of "fees" (e.g. gas fees in Ethereum blockchain). Coins can also be used to perform tasks on the blockchain, for example, the Ethereum blockchain is widely used for decentralized applications and uses coins as a form of payment for recording information of any sort (e.g. videogame advancements, the creation of an NFT). Moreover, being used by blockchains, cryptocurrencies inherit all the features of blockchains being cryptographic, peer-to-peer, and transparent.

We can consider Bitcoin to be the first cryptocurrency, although there had been some small attempts at creating a digital currency before the invention of Bitcoin. Bitcoin was created in 2008 after the financial market crash, the motif was the dissatisfaction with the financial system, Bitcoin was therefore created as a replacement for traditional currencies that would make the market more secure, transparent, and decentralized. One important concept to understand about cryptocurrencies is the mining process. Mining refers to the creation of new cryptocurrencies that happens as a form of incentive for nodes to record transactions. Before a new block is added to the chain there is a sort of race among nodes to be the one to validate the new block and append it to the chain, the node that wins this "race" is rewarded with a certain amount of coins that depends on the specifics of each individual blockchain. This creation of currencies resembles the printing of money, although it would be a predictable amount based on the amounts of transactions happening on the blockchain. For example, in the Bitcoin blockchain, the number of coins being awarded is halved after a certain number of coins have been mined, bringing a limit to the maximum amount of bitcoins that can ever be created. A lot of the criticism of cryptocurrencies centers around whether they can or cannot be considered "money" or if they are just worthless and should be considered as a scam. To better formulate an answer we should consider different cryptocurrencies since they all have different features and could potentially fall under certain definitions of money.

Although there are more than 23,000 cryptocurrencies in existence today (coinmarketcap 2023), they can be divided in four major categories: payment cryptocurrencies; utility tokens; stablecoins; and Central Bank Digital Currencies (CORPORATEFINANCE 2023). Payment cryptocurrencies are used as an exchange of value, but also as peer-to-peer electronic cash for transaction purposes, they are usually limited in quantity through an algorithm that reduces the quantity of coins that can be mined with time and therefore are deflationary by nature. Utility tokens base themselves on other blockchains and have specific uses on the blockchain using them, for example, on the Ethereum blockchain they are used to pay transaction fees, purchase digital assets or pay for digital services. Utility tokens are not capped and therefore can be generated infinitely, giving them an inflationary nature similar to traditional currencies. Moreover, tokes can have very specific uses such as giving ownership of a certain digital asset in the case of NFTs, or even giving the owner of a certain token voting power on changes that could be made to the structure of a blockchain.

Now that we know more about the nature and characteristics of different cryptocurrencies we can better see if they fall under any of the following theories of money: chartalism; metallism; or functionalism. It would be hard for public cryptocurrencies to fall under the theory of chartalism since it implies the legal creation by the government, not even Bitcoin, which is recognized as national currency by El Salvador can fall under this theory since it is not created by the government. On the other hand, there are some digital currencies that are being created by governments which could fall under this category, as of December of 2022 there were 11 digital currencies issued by central governments although many more are in development (CBDCT 2023). When it comes to metallism, which requires money to be reflective of the value of an asset, the discussion is more complex since we should distinguish between stablecoins and all other currencies. Stablecoins are pegged to some already existing asset (dollars most commonly), similarly to how the currencies of the world were pegged to gold during the gold standard and could be considered money under this theory. Lastly, if we want to use the theory of functionalism we need to address three points. For something to be considered money it needs to be a means of payment, a unit of account, and a store of value. A lot of cryptocurrencies fail at being a store of value because they tend to have high levels of volatility, making their value change significantly in short periods of time.

On the other hand, the high levels of volatility seen in most commonly used cryptocurrencies may be due to the relative newness of this technology and could become smaller over time, making cryptocurrencies fall under all of these categories. Whether cryptocurrencies are money or not is still up for debate and is not the central topic of this thesis, but this is an important point to address because the adoption of cryptocurrencies in everyday life might also depend on whether they are money or not. Today the adoption of cryptocurrencies is still in its early stage, but more and more businesses have started to accept them as a form of payment and according to a survey from HSB, in 2020 about one third of small businesses accepted cryptocurrencies as payment (HSB 2020), this could lead to a point where their use will reflect that of traditional currencies, but their value will still fluctuate excessively causing capital shortfalls for businesses which might lead to increased systemic risk. This discussion is also important in relation to the trust that people have in this new technology, lack of recognition as money may lead people to view cryptocurrencies as scams which may cause runs and panics which would collapse the crypto markets. Overall, whether cryptocurrencies are money or not is still up for debate and is not the central topic of this thesis, for more information about if cryptocurrencies are money please refer to "Are Bitcoin and other crypto-assets money?" by Gabriel Söderberg (2018).

One of the biggest concerns regarding cryptocurrencies lies in their unregulated nature. Many cryptocurrencies have been used to commit frauds, or have been used to engage in illegal activities (e.g. money laundering), this situation could pose threats to the market in at least two different ways, the first being the risk of loss in market confidence, the second is the risk that regulators might ban the use of certain blockchains or cryptocurrency exchanges (e.g. UK and Binance). Nonetheless, the issue of market confidence continues to reduce as the market becomes mature and the legitimate projects outperform the fraudulent ones, moreover, completely banning cryptocurrencies would not necessarily be a great way to regulate the market due to difficulties in achieving so and also because this technology has shown potential for reducing transaction costs and improving transaction speed.

Chapter Four: Systemic Risk in Crypto Markets

Now that we have a better understanding of the capabilities of blockchain and cryptocurrencies I will review what scholars have been saying about systemic risk in relation to cryptocurrencies and blockchain. Starting with cryptocurrencies, there are two ways in which the literature has addressed systemic risk: (1) systemic risk sharing among crypto markets and traditional markets; (2) systemic risk sharing within the crypto market.

Systemic Risk Sharing Between Cryptocurrency Markets and Traditional Markets

The literature on this topic focuses on the transmission of systemic risk from cryptocurrency markets to traditional markets and vice versa (although the focus is mainly on the transmission from crypto markets to traditional ones). The goal is to determine if cryptocurrency markets are becoming systemically important to the point that a shock within the crypto markets could affect the entire economy. As shown before, cryptocurrencies have been growing since their inception and have gained attention thanks to the size and volatility of their market, for this reason some institutions are showing concern and calling for the regulation of this new market (see BIS 2023 or IMF 2021 for example).

To determine if the concerns are appropriate, or if they are an overstatement of the issue, we can look at how the literature on systemic risk and cryptocurrencies has evolved with time. Using articles from different time periods we can assess whether cryptocurrency markets have shown any evidence of becoming systemically important over time.

One of the first articles on this subject is the one from Makrychoriti and Moratis (2016) who studied the Bitcoin market in relation to the traditional markets. Using only Bitcoin at the time made sense since Bitcoin was responsible for approximately 85% of the total market capitalization of cryptocurrencies (coinmarketcap 2023). In their study, Makrychoriti and Moratis (2016) attempted to determine if Bitcoin was affected by shocks in traditional markets, since Bitcoin was still a relatively new asset there was no concern that it could affect traditional markets at the time. After testing Bitcoin's response to shocks in volatility, interest rates, and market confidence indicators, they concluded that what drove Bitcoin's price to change were only investor sentiment and factors specific to Bitcoin as a technology. A similar conclusion was reached by Baur et al. (2018) who conducted a similar study on 2010-2015 data and found no correlation between Bitcoin and the S&P500. Although they found similar results to Makrychoriti and Moratis (2016), Baur et al. (2018) added that Bitcoin was mostly being used as a method of investment rather than as a technology for exchanging value. Both these studies suggest that Bitcoin and the crypto markets were still a niche category of assets and did not pose any significant threats to traditional markets. A big change happened in 2017, when the cryptocurrency market gained visibility and by the beginning of the following year had reached a total capitalization of approximately 800 billion USD and Bitcoin's share of the market cap had dropped below 50% (coimarketcap 2023), meaning that the market had gained interest beyond Bitcoin.

Fast forward a couple of years and we get a new article by Li and Huang (2020) who were able to include in their study data that reached the end of 2019. The objective of their study had slightly shifted compared to the studies already discussed, they were trying to find any presence of volatility spillovers between crypto markets and traditional markets. What they concluded is that the crypto market remained to appear isolated from traditional markets and did not pose a threat, they also found that volatility spillovers occurred within the cryptocurrency market (for more details about systemic risk within crypto markets see the next section). The results suggested once again that crypto markets were still not a threat to traditional markets, at the same time, the authors pointed out that crypto markets could divert funds from traditional markets in times of low systemic risk since the perspective of higher returns in crypto markets would make them seem more appealing to investors.

The speculation around cryptocurrencies that happened during the Covid19 pandemic led to new research. Hakim and Syuhada (2023), who analyzed data including the 2021 crypto market bubble, found evidence that crypto markets were transmitting systemic risk to traditional markets such as oil, the S&P500, and gold. They also concluded that the systemic risk transmission from crypto markets to traditional markets was not as significant as the systemic risk transmission happening within the crypto markets.

In summary, there seem to be support to the claim that crypto assets can become a source of financial instability and systemic risk. Although at first the market was very small and not interconnected enough to traditional markets, as time goes by and crypto markets become larger with more investors dedicating a portion of their portfolios to these new assets, the potential for systemic risk events starting in the crypto market and expanding to traditional markets will likely increase. The ways in which this might happen can be summarized as: reduce funds and liquidity from traditional markets, potential scams and frauds in the crypto environment leading to investor uncertainty and runs, high volatility in crypto markets that leads to severe losses to investors. Luckily, crypto markets and traditional markets are not yet connected enough (see BIS 2023, and IMF 2021) and there is still time for regulators to take control of the situation.

Systemic Risk Sharing Within the Crypto Market

Since it seems that crypto markets are becoming more correlated to traditional markets over time, we also need to address the systemic risk within these markets. Due to the seemingly increasing connection between crypto and traditional markets, a systemic event within crypto markets could have an impact on traditional markets as well.

Before looking at the literature we must acknowledge one major aspect of cryptocurrencies, they are a new technology and useful data has become available mostly after the 2021 and 2022 crypto bubbles. We should keep in mind that before the end of 2017, the crypto market was dominated by Bitcoin which was responsible for more than 80% of the entire market, after 2017 the market became more diversified (coimarketcap 2023). After 2017, Bitcoin's market share has fluctuated between 35% and 70%, while the combined market shares of Ethereum and Bitcoin fluctuated between 50% and 80% and now stand at around 70%. This indicates that the market is still dominated by a few cryptocurrencies (the top 10 hold 85% of the total market cap) and the studies might be conditioned by this factor. Secondarily, there are a few notable events that should be keep in mind when talking about cryptocurrencies. The first one is the bubble and crash at the end of 2017 that brought visibility and interest to the crypto markets, in that year the market grew by 40 times from about 20 billion to more than 800. Two more bubbles and crashed happened in 2021. In that period, cryptocurrencies reached almost 3 trillion USD in total market capitalization, only to then crash to one half of the peak capitalization (coinmarketcap 2023). Lastly, in 2022 the stablecoin TerraUSD lost its peg to the dollar and caused another loss in confidence in the crypto market which once again halved the market capitalization. The last notable event that happened in relation to the crypto market is the bankruptcy filing by one of the largest crypto exchanges, FTX, in 2023. Keeping these events in mind I will now go on to review the research that has been conducted and determine what sources of systemic risk are present in the crypto market.

Moving on to the literature on systemic risk within the crypto market, the most common methods used by scholars involve measuring different sources of systemic risk, mainly tail-risk spillovers, interconnectedness, and contagion in the crypto market (see Nair and Kayal 2022, Xu et al. 2020, Borri 2018, Ji et al. 2018, Zhang and Ding 2021, Moratis 2020, Akhtaruzzaman et al. 2022, Liang et al. 2018, Jalan and Matkovskyy 2023, Ahelegbey et al. 2020).

Starting from the most recent events, Jalan and Matkovskyy (2023) conducted a study to determine if the event had any significant impact on systemic risk. They used a macroeconomic measure called CATFIN, that is estimated using VaR and expected shortfall methods, and determined that the levels of systemic risk had not been affected by the bankruptcy of FTX, nor by the collapse of TerraUSD. On the other hand, Jalan and Matkovskyy (2023) speculate that the failure might be due to bad corporate governance rather than being a failure of cryptocurrencies. This results would give us a positive outlook when it comes to systemic risk within cryptocurrencies, at the same time I need to emphasize once again the fact that the market is mostly composed of a few cryptocurrencies which could explain why the failure of TerraUSD did not have a major impact on the market. Another finding by Jalan and Matkovskyy (2023) is that the biggest increase in systemic risk levels was during 2021. Their results are similar to the findings of Akhtaruzzaman et al. (2022) who determined that the higher levels of systemic risk were due to an increase in interconnections in the market during the covid-19 pandemic. These findings showed what the changes of systemic risk level were but did not give us much insight as to the level of systemic risk itself, in the next section I will review articles that address the level of systemic risk and the overall fragility or robustness of the crypto market.

To address the level of systemic risk within the crypto market, many studies have used the correlation among cryptocurrencies as a proxy. Several studies found excessive correlation between cryptocurrencies in the period around the 2017 boom and bust (see Gkillas et al. 2018, Borri 2018, Liang et al. 2018). These results might have been influenced by the infancy of the market, yet more recent studies such as Ahelegbey et al. (2021) and Ji et al. (2019) also found correlations among cryptocurrencies, adding that the correlations were particularly strong during periods of decline. Another branch of studies focused on determining which cryptocurrencies were the major emitters or receivers of systemic risk in the market although the results seem discordant. Nair and Kayal (2022) and Xu et al. (2021) found Bitcoin to be the largest systemic risk receiver and Ethereum to be the largest systemic risk emitter, on the other hand Ahelegbey et al. (2021) found that Bitcoin was one of the major risk emitters, while Ethereum was a risk receiver. One explanation for these discording results is brought by Ji et al. (2019) who observed that cryptocurrencies would alternate between being emitters and receivers of systemic risk depending on the period. One factor remains, the most commonly used cryptocurrencies are usually the top emitters or receivers, meaning that this market is still highly affected by the fluctuations of the largest players. We could in some way see Bitcoin and Ethereum as a crypto version of TBTF that could directly affect the entire crypto market, especially when they are emitters of systemic risk. The study conducted by Ahelegbey et al. (2021) also introduces an important division in the crypto market. They divide cryptocurrencies in “speculative” assets and “technical” assets. “Speculative” assets, such as Bitcoins, are the ones that have been observed to be a source of contagion, these assets usually do not have many practical uses besides being a medium of exchange. On the other hand, “technical” assets, such as Ethereum, have been observed to be receivers of contagion and are usually assets that have other uses, for example Ethereum can be used to run applications on the Ethereum blockchain. This would create a sort of division in the cryptocurrency market, and my speculation is that as time passes, the market size of “speculative” assets will be slowly reduced and replaced by “technical” assets that will be used to perform daily tasks. Perhaps Bitcoin will retain an importance in the market, but that could be due to its status as a symbol of cryptocurrencies rather than its usefulness.

Lastly, talking about Bitcoin, some people compare it to gold, and this is mainly due to its algorithm that limits the total supply and makes it scarce. To add to the discussion, Zhang and Ding (2021) and Akhtaruzzaman et al. (2022) observed that Bitcoin remained relatively stable in the long-run. Akhtaruzzaman et al. (2022) also found Bitcoin to be less vulnerable to systemic risk. These findings would suggest that Bitcoin could be seen as a replacement for other cryptocurrencies in times of market instability, similarly to how gold is treated in traditional markets. Unfortunately, the market is still in its early stages, and the effects of the most recent crypto crashes are being observed right now, saying whether Bitcoin can be the crypto version of gold or not might still be early, but the signs indicate that it does have the potential to achieve that status.

Reflections

Cryptocurrencies seem to be becoming increasingly correlated with traditional markets, and this correlation might cause future concerns for traditional markets' stability. At the same time, it seems that the crypto markets are still a minor threat to traditional markets, but regulation for the prevention of future problems should be a pressing matter for governments. The BIS, in their 2023 report also advocated for Central Banks to start developing their own digital currencies to substitute the need of cryptocurrencies as a less costly and quicker method of exchange.

When it comes to systemic risk within the crypto markets, research has shown that the major sources of risk are high levels of correlation among cryptocurrencies, and high potential for systemic risk transmission from and to the major players. Unfortunately, the crypto market is still dominated by only a few major currencies which significantly impact the changes that happen in the market. There does not seem to be any evidence that cryptocurrencies have the ability to reduce systemic risk within the crypto market, and as of today there seems to be evidence that they actually have high levels of systemic risk because of the excessive correlation among them.

In the next chapter I will move away from already existing blockchains and cryptocurrencies and address the areas in which the technology might be capable of reducing specific sources of systemic risk.

Chapter Five: Systemic Risk Reduction in a Blockchain Financial System

This chapter briefly explained the major characteristics and main capabilities of the blockchain technology, in the following section I will attempt to explain how this technology can help reduce systemic risk. I believe an implementation of blockchain technology could reduce systemic risk by allowing regulators to have a better understanding of the state of the economy. I will briefly review what the literature has focused on and then proceed to give a personal assessment of areas in which blockchain could benefit the talk about systemic risk for future research. As in the chapter about systemic risk, I will divide the discussion in three parts, reviewing systemic risk taking, contagion, and amplification mechanisms.

Literature Review

There is extensive literature that talks about the impact of current blockchains on systemic risk in traditional markets and within blockchains, yet there are not many articles that look at the potential positive or negative impact that this technology may have on systemic risk. In this section I will go over the few articles that address the potential benefits and risks that blockchain technology can have on systemic risk. Most of the research so far has been focused on OTC markets and the increases in transparency that could facilitate the work for regulators.

Starting with Avgouelas and Kiayias (2019), they find that DLT can bring increases in the visibility of risk, but also in the visibility of positions that market participants take, they also add that the technology could reduce costs to end investors and other users while improving transparency and liquidity conditions for long-term investments. Another point they make regards the fact that the increased transparency might curb speculative behavior fueled by high leverage. This is an interesting consequence of the increased transparency, although it could be a cause of rejection of the technology from speculative institutions. They also consider the possibility for central counterparties to continue existing, functioning as intermediators for complex and risky contracts, this scenario would imply that the majority of OTC derivatives will be traded through a DLT system, making central counterparties smaller and less important systemically thanks to their reduced size.

Similarly to the previous article, also Jayeola (2020) and Patsinaridis (2018) focus on over-the-counter (OTC) transactions and on the potential that blockchain has to improve the transparency in those markets. These articles discuss the lack of transparency and the lack of consistency in trade reporting in OTC markets which limit the ability of regulators to monitor the markets and systemic risk, making it more difficult for regulatory agencies to take quick action in the event of a crisis. Moreover, Jayeola (2020) makes the point that regulation enforcing trade reporting is costly, therefore recommending the use of blockchain technology to reduce these costs and make the reporting process automatic thanks to the transparency that a blockchain infrastructure provides. A similar conclusion is also reached by Patsinaridis (2018) who claim that DLT can help improve regulators' oversight and monitoring capabilities.

On a more cautious note, Surujnath (2017) focuses on public blockchains and concludes that although there is potential for the reduction of risks related to over-centralization, blockchains may cause other types of risk to arise. These risks include cyberattacks, but also unforeseen risks related to the new financial assets that could develop on a blockchain which could undermine the trust that users have on this technology. This weakness is more prevalent among public blockchains since anyone would be allowed to record transactions and malicious nodes would be more likely to exist. In a private or consortium blockchain the nodes would all be approved and trusted agents, reducing the risk of malicious recording of transactions. Surunjath (2017) also encourages regulators to be cautious and suggests that future research on blockchain and systemic risk should be performed by those who have a good understanding of the technology as well as of law and finance.

Mselmi (2020) takes a different approach, assessing the impact that blockchain technology had on 40 financial institutions to determine if there was an impact on systemic risk for institutions that migrated their management to blockchain systems. Using the measures "SRISK" and "LRMES", Mselmi (2020) finds that the financial institutions that did not migrate to a blockchain system recorded higher levels of systemic risk. On top of systemic risk, the results suggest that also operational risk was reduced for the financial institutions that migrated to a blockchain system, suggesting that there is incentive for more institutions to do so.

Besides these articles, the other ones that I could find mostly focus on the impact of existing blockchains or cryptocurrencies on traditional markets which we have already discussed. What I could not find were articles that studied the potential impact of a blockchain financial system on systemic risk in a more complete manner. As mentioned, most articles focused on some benefits to systemic risk that could be achieved through the use of specific applications of blockchains for individual corporations (e.g. Mselmi 2020) or through the use of already existing public blockchains (e.g. Surujnath 2017). Only Avgouelas and Kiayias (2019) make an analysis that takes into consideration several aspects and types of blockchains, although they focus mostly on OTC markets and do not address the potential of blockchain in more general markets.

In the next section I will discuss possible applications of blockchain technology and how they could reduce systemic risk. The discussion could be used as a starting point for future studies that would contribute to the literature on systemic risk by providing more insight on the potential benefits and drawbacks of blockchain technology.

Systemic risk taking

Blockchain technology can be used to impact several systemic risk taking behaviors and discourage them. The programmability of blockchain technology can be used to incentivize certain behaviors and discourage others. Moreover, thanks to its transparency and traceability, blockchain could allow regulators to better monitor the market.

Correlated Investment

Starting from correlated investments, we can say that it would be difficult for a blockchain to prevent financial institutions from partaking in similar investments, for this reason I find it difficult that blockchain could solve this problem. On the other hand, the transparency that would be achieved thanks to the blockchain structure would allow regulators and financial institutions to monitor how correlated the investments are with other institutions, allowing regulators to take preemptive action if they perceived an increase in systemic risk.

A risk for this specific source of systemic risk would be that many small financial institutions could start mimicking larger institutions to increase the likelihood of bailouts from the government in case of failure as explained by Acharya and Yorulmazer (2008) when they talk about the problem of too-many-to-fail.

For the reason above, a hybrid blockchain administered by regulators and the Central Bank could be a solution to this issue. Financial institutions and other market players would be allowed to transact with each other, yet only regulators would have access to the full picture and act accordingly when they believe that the correlation between investments is too high.

Too-Big- /Too-Interconnected-To-Fail

Similarly to the issue of correlated investments, blockchain does not seem to be capable of stopping financial institutions from growing too big or too interconnected, yet there are at least two factors that should be explored. The first is the potential to place “fees” for creating new interconnections through the use of smart contracts, if a financial institution wanted to make a transaction that would create a connection with a different institution, the blockchain could recognize the impact of this transaction and place a cost on it. The receipts from the cost of “risky” transactions could be then put toward a crisis fund, this would allow the government to let financial institutions default since their shortcomings toward other institutions could be covered through the use of the fund.

The second factor is the traceability of blockchain. In the event of a failure from an institution, regulators could be able to pin-point what other institutions are at risk of default because of their interconnectedness to the defaulting institution and act immediately to mitigate the situation and prevent it from starting the domino effect that is typical of systemic risk crises.

Liquidity Risk

When it comes to liquidity blockchain could have an impact in at least two ways. Firstly, by making it easier for institutions to connect and redistribute liquidity in the market, secondarily, by changing the cost of transactions and giving a boost in liquidity to markets that need it.

Thanks to blockchain connectivity and programmability, different market players could devise smart contracts that automate the sharing of funds at a predetermined interest rate. This would allow market players that have excess liquidity to share the liquidity with banks and other financial institutions that need it, therefore increasing the pool of funds that banks have access to when they are seeking liquidity. To give an example of how this could work, we can imagine a smart contract developed by banks that allows investors to join, the smart contract would keep track of all the non-invested funds among the pool of banks and investors, when a bank is short on capital due to the maturity mismatch of its assets and liabilities it would put a request for funds on the network and receive capital at a specified interest rate from the pool of non-invested funds. The amount of non-invested funds could also become a proxy for market stability or systemic risk. It must be acknowledged that this possible feature of blockchain would not necessarily solve the liquidity issues in the economy during a crisis, if people lose confidence in the economy, they would perhaps remove their funds from this hypothetical program, making this a solution for minor liquidity issues rather than a solution for major crisis.

When it comes to liquidity in specific markets, smart contract could once again be a solution. As explained by Yang and Zhange (2021), transaction costs can affect liquidity, higher transaction costs may have a negative effect on liquidity (see also Elliott 2015). Transaction costs are not only direct fees or commissions on the transaction but also include the bid-ask spread and the potential loss incurred when choosing a bid price which is lower than the market price to quickly sell the asset (Elliott 2015). Although blockchain cannot affect the bid-ask spread of a certain asset nor the price movement in the market, it can affect the explicit costs such as commissions. As shown by Al-Jarodi and Mohamed (2019) and Ahluwalia et al. (2020), blockchain has the potential to remove commissions, allowing markets to be more liquid.

I believe that fully removing transaction costs might not be desirable since it could create a situation in which short-term speculations become more frequent, instead I would suggest the use of smart contracts to manipulate the explicit costs of transaction.

For example, smart contracts could be designed to reduce fees or commissions on transactions when the bid-ask spread becomes too wide, balancing the cost of transactions throughout different markets. This idea of using transaction costs to reduce speculators' investment in markets has been explored in the literature, producing various results. Fu et al. (2016) for example find that a 2/3% increase in transaction tax led to a 75% reduction in speculative trading. The reduction was mostly in informed speculators, while noise speculators kept investing and caused the price volatility to increase. Assuming that investors will continue seeking investment opportunities, they will necessarily find opportunities with lower transaction costs to continue their speculative investing. This idea is also supported by Baker (2010) who claims that "traders will absolutely try to switch from assets where the trades are taxed to assets where they are not taxed", confirming the theory that the liquidity in the market can be directed to areas where it is most needed by controlling the cost of transactions and making the programmability of blockchain an even more desirable tool for regulators.

Tail Risk

Once again, the informational potential of blockchain could be key to improving systemic risk visibility, and in this case allow regulators to know what a three or more standard deviations move would imply. It could also allow regulators to have knowledge about some of the practices of shadow banks, their investments might still be unregulated, but they would not fall under the radar thanks to the transparency provided by blockchain, and regulators would be able to take quicker action in case of a crisis. Besides this, I do not see how the technology could reduce tail risks, at the same time I do not see how it could make it worse either. Tail risk has more to do with the type of investments that financial institutions make, and the blockchain technology cannot force institutions to change their investment strategies.

On the other hand, there is an argument as to how tail risk might increase because of the blockchain technology. Making peer-to-peer connections easier would allow more individuals and firms to engage in lending and borrowing activities while avoiding regulations, similarly to how shadow banks operate. Although smart contracts could be used to enforce a fee for lending and borrowing without regulation, this topic should be studied more in depth to have a clear answer as to if it could be a potential drawback or if it is an easy to solve issue.

Contagion

Contagion has been shown to be an important factor of systemic risk. In the previous chapter we discussed the differences between balance sheet contagion, payment and clearing infrastructures, and informational contagion. Before going into the details of each type of contagion and how blockchain technology could help I want to give a brief summary of what I suppose the benefits of blockchain could be. I believe that the benefits in balance sheet contagion would once again be related to the augmented information provided by blockchain. When it comes to payment and clearing infrastructure, blockchain technology could bring significant advantages (but also risks) by revolutionizing the way we process payments and transactions. Lastly, blockchain can have a significant impact on informational contagion thanks to its transparency.

Starting with balance sheet contagion, the idea is similar to the one of interconnectedness, if we record all transactions on blockchain and regulatory agencies have the ability to see what happens at all times, then they can also have access to updated balance sheet information at any time. This could give regulators the ability to keep track of the exposures of financial institutions and intervene rapidly if they notice troubling signs. In the event of a failure from a financial institution, they could quickly react by addressing the relations that the failing institution has to others in the economy. The improved information could also be used in conjunction with the findings of Battiston et al. (2012) by addressing the level of completeness of the financial network and using this measure as a proxy for systemic risk.

Next, we have payments and clearing infrastructures. As mentioned in the previous chapter, CCPs have been addressed in the literature as being a potential source of systemic risk, having them as the only entity responsible for clearing certain transactions could lead to significant issues in the case of a CCP failure. This weakness is not shared by blockchain technology thanks to its decentralized and distributed nature. In a blockchain network, since all nodes have the same role of validating and recording transactions and they have access to the same information, for the network to fail it would mean that all nodes have failed, which becomes less and less likely the more nodes are present in the network, reducing significantly the risks of network failure since a blockchain could theoretically run even on a single node (Web3 &amp 2023), meaning that even if all but one nodes were to fail, the network would survive and continue operating. Therefore, blockchain technology might be a good substitute of CCPs since it can perform the actions of clearing and recording transactions but does not share the centrality of CCPs and all the risks that come with it. Avgouelas and Kiayias (2019) claim that some simple CCPs functions could be performed by a blockchain infrastructure to facilitate their operation, CCPs could retain the role of overseeing the recording of some of the more complex financial instruments.

Lastly, informational contagion could be reduced by using blockchain technology thanks to the transparency that blockchain can provide, reducing informational asymmetries. Having higher transparency in the market when it comes to the relations of financial institutions would reduce uncertainty about which institutions are at risk of failure, avoiding panics by investors who have their funds in safer institutions and would not have been able to assess the safety of their institution in traditional markets. On the other hand, the increased information sharing would make it more likely that investors would withdraw their funds from struggling financial institutions, but one could argue that the risks would be easier to address and the tendency by investors to overreact could be reduced. At this time it is not obvious to me if the informational advantages would outweigh the potential for more frequent runs in distressed institutions, although thanks to the programmability of blockchains it could be possible for regulators to disclose information only when deemed beneficial to investors and markets in general.

Chapter Six: Conclusions

This thesis has tried to evidence a missing link in the literature on systemic risk. Although the literature on systemic risk has been relatively quick to start including blockchains and cryptocurrencies, it has done so by focusing on the strengths and weaknesses of already existing blockchains, without considering the possibilities that this new technology could have if applied with specific features in mind.

After reviewing the literature on systemic risk, I was able to determine that the key factors to consider when addressing systemic risk are risk taking behaviors such as correlated investments, too-big/too-interconnected-to-fail corporations, liquidity risk, and tail risk. These are the factors regulators should be careful about when trying to prevent systemic crisis from happening, therefore, being able to more easily assess such systemic risk taking behavior in the market can be beneficial for the economy since it could help prevent systemic events from happening. On the other hand, if a systemic event were to happen, it would spread in the economy through contagion or amplification mechanisms. Contagion and amplification mechanisms can be caused by different market factors such as asset and liability sharing by financial institutions, the payment and clearing infrastructure that could be too centralized, informational asymmetries that could cause panics or runs, but also by liquidity issues in the market.

To address systemic risk and blockchain technology I started by reviewing what the literature was saying about existing blockchains and cryptocurrencies. According to the literature, the cryptocurrency market is becoming more interconnected with traditional markets which could become problematic since as of today the crypto market shows high levels of systemic risk. This is mostly caused by the interconnectedness among cryptocurrencies which may also be caused by the predominance of a few major coins. A positive light was shed by the recent cryptocurrency crash of stablecoin TerraUSD that did not seem to have increased the level of systemic risk in the market.

Lastly, I proposed some potential improvements that the blockchain technology might bring to the financial market. These mainly rely on features unique to blockchains such as reduced transaction costs and transaction time and the transparency potential of blockchain technology that might be able to reduce informational asymmetries. Another important aspect of blockchain are smart contracts which allow specific features and applications to be programmed on blockchains, these features might render risk increasing transactions more costly, or provide incentives to increase liquidity in specific markets.

Overall, blockchain technology has the potential to revolutionize the financial system, bringing many improvements, but also potential risks if not done properly. This thesis wants to encourage research to explore the potentials and risks of this technology so that when governments decide to implement it in financial systems they will do so in a more informed manner and can avoid mistakes. Similarly to every technological invention that has shaped the financial market, the benefits and risks are not apparent at first due to a disconnection between the knowledge of the financial markets and the capabilities of the new technology. It is for this reason that economic researchers should join forces with computer science engineers to conduct research on this new technology to guide regulators and governments to develop the technology in the best way.

As mentioned in the introduction, the changes to the financial system could have an impact on individuals and firms, and could certainly bring benefits if done properly, but they could also come with unforeseen problems. One example of this double side of blockchain could be seen in the peer-to-peer connections. On the positive end of things, they would allow for an easier flow of capital to where it is more needed, bringing benefits and potentially reducing the illiquidity in certain areas of the market. On the negative side, it could promote different ways for lenders to avoid regulation, creating thus a new form of "shadow banking" that could create instability in the market. For this reason, I suggest that the change should happen gradually, starting with pilot projects would be a great way to start seeing the potential benefits and drawbacks of the technology without great risks. One first implementation could be to use blockchain to record OTC transactions, this could allow financial institutions to start adapting to the concept of blockchain, it could also allow regulators to formulate better assessments about what happens in those markets. Another approach could be to start using blockchain based systems to record transactions on smaller stock exchanges to better address the benefits and challenges that such change could bring. Other projects could also involve central banks developing a government stablecoin that could be used in everyday transactions. Later, if the first projects had been successful, there could be room for expansion of the blockchain based financial system, allowing for more tasks to be performed by a blockchain, with all the benefits that it would bring.

Hopefully this thesis can be the basis for future research on systemic risk and blockchain technology by providing a general framework of what researchers can focus on when discussing this topic.

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