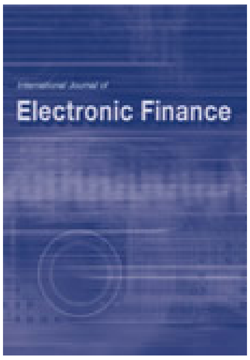

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A survey of systemic risk in the banking industry

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Abstract: The paper surveys the systemic risks in the banking industry, characterising the risks according to the risk source and market transmission mechanism. The corresponding approaches that could be leveraged by regulations to minimise such risks are meticulously analysed. Diverse isolated sources of systemic risk could be managed using differential measurements for separate sources using various data-based financial ratios and regulation tools. More sophisticated approach is the integration of various global measures, which are aimed at regulating systemic risk without specific sources, and it uses market data to operate a more efficient regulation. In this paper, detailed comparisons in terms of the advantages and disadvantages of these regulation tools and measures are discussed and suggestions for more robust future regulation are also provided.

Keywords: systemic risk; risk transmission; regulation tools; financial ratios; integrated measures.

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1 Introduction

In the whole financial market, banks play a significant role in sustaining economies. In order to survive, banks need to invest, hedge risks to make profits, and interact with peer banks to coordinate and compete. For example, banks tend to join in the same position of the same assets or portfolios, which is so risky that their values will fall together in a crisis (Acharya and Yorulmazer, 2008). They lend to each other and help each other within the interbank market, and they are also connected through their customers. In 2007, the default of some banks in the US propagated risks as a contagion in the banking system, which led to several banks going bankruptcy including Lehman Brothers, and finally caused the financial crisis from 2007 to 2009. This crisis is caused by many different and complex reasons, and the potential systemic risk in the banking system can be a significant one of them. Hellwig (2009) focuses on systemic risk analysis and concludes that the systemic elements lead the subprime mortgage-backed securities crisis in the USA to a financial crisis across the world. Attracted by the risks that banks are sharing and how to regulate systemic risk via different methods to ensure the whole system is stable, we determine to survey the approaches to regulate systemic risk in the banking industry. With the experience learnt from the financial crisis and adequate preparation knowledge of systemic risk, we can get ready for future crises and even prohibit them from happening to ensure the banking system keep energetic and stable.

In this report, the first part reviews literature in the field of systemic risks covering sources and regulation tools. For the methods section, the first part describes three main sources inducing systemic risks which are systemic risk-taking, contagion, and amplification in detail, and for each source, its transmission of the channel will be displayed. The first source of systemic risk is systemic risk-taking, explaining why banks' investments are both correlated and large. The second one is the contagion mechanism, through which the loss of one institution will spill to the other ones in this system. And the last one is the amplification mechanism, which means a small shock can generate a large effect on the financial system. Then, for each specific channel of risk, targeted regulation tools will be introduced to tackle systemic risks like market index regulation. These methods often use supervisory data to give predictions to control systemic risk and ensure the financial market is stable. A detailed explanation of why such a source of risk should be regulated with such a tool will be shown. The second part will propose global measures which investigate how much systemic risk an institution contributes to the whole system without identifying the source and the transmission of risks. These global measures are greatly associated with the market risk measurement tools, including marginal expected shortfall (MES) and systemic expected shortfall (SES), systemic risk measure (SRISK), and delta conditional value-at-risk (ΔCoVaR). With the use of both types of these measures, systemic risk can be regulated effectively. Next, the evaluation and comparison of these two main approaches will be deliberated. Note that all the regulation tools and measures from these two parts will be discussed with superiorities and shortcomings. In general, more integration and connection need to be built between these two types of measures. For example, when encountering complicated situations such as the difficulty which is hard to distinguish which channel leads to risk, global measures can be used to complement this risk supervision system. Regulation authorities should combine both of these two main kinds of measures with mutual complementation to implement systemic risk regulation. Lastly, the fourth part consists of suggestions and a conclusion for system risks and regulation tools in the banking industry, by referring to which regulators can measure and regulate systemic risk with new ideas and approaches.

2 Literature review

In order to survey this field thoroughly, we research a lot of related literature. Different papers define 'systemic risk' in many ways. Kaufman and Scott (2003) define it in two ways. The first definition is from a macroeconomic view, which refers to a large shock affecting most of the institutions at the same time in the system. The second one is from the microeconomic aspect, which refers to the negative externalities of other institutions. Smaga (2014) defines that systemic risks are the risks that a large shock will propagate widely and lead to financial instability in the whole economy. Here, we describe systemic risks as the risk that a large number of market investors are hit by large losses at the same time, and then the losses spread across the system. According to Acharya (2009), if many banks go bankrupt simultaneously, or if one bank's severe losses propagate and lead to the failures of other banks, then the financial crisis is said to be 'systemic'.

Systemic risks can be generated by many different kinds of sources. For example, the correlated investments undertaken by all banks will increase economy-wide aggregate risk. Acemoglu et al. (2015) claim that the connected network formed by banks reinforces financial stability when the shock is sufficiently insignificant because some affected banks can get financial aid from other banks within the interbank market. However, the interconnections will propagate shocks and result in a more fragile banking system when the shock is beyond a certain point. This is because, in crises, most banks in this system will ask for help, but no one can give any financial support because all most institutions are affected and are facing a crisis. Allen and Carletti (2013) classify the sources of systemic risk into four types which are panics, banking crises, contagion and foreign exchange mismatches. They claim that systemic risk is generated from the reciprocal action between the markets and financial institutions, and it would lead to a financial crisis.

Considerable earlier studies have been done regarding the systemic risks in the banking sector. Bisias et al. (2012) provided a survey of 31 quantitative measures of systemic risk for regulators and market participants to measure and monitor financial stability. They introduce each measure with key themes and issues, which is convenient for regulators to choose and deploy from different operational directions. Neveu (2018) proposed network analysis and agent-based modelling approaches to better understand contagion and detect fragile systems before collapse. Khiari and Nachnouchi (2018) developed a statistical framework to assess systemic risks from two aspects, which are banks ranking of systemic implication and influential vital variables, such as VaR and CoVaR. Chen et al. (2021) illustrate that the design and implementation of regulation should be paid more attention to. They found the impact of bank supervision on systemic risk is through bank's capital shortfall. Thus, supervisors should design certain regulation framework for banks based on their level of equity and bank size, which are vital variables related to the capital shortfall.

Table 1 Outline of main sources of systemic risks and the corresponding regulatory tools

Sources		*Tools*		
Systemic risk-taking				
Correlated investments	Acharya (2009), Acharya and Yorulmazer (2008) and Farhi and Tirole (2012)	Regulation tools	Capital ratio	BCBS (2011), BCBS (2014b) and Ono et al. (2013)
Liquidity risks	Bhattacharya et al. (1985)		Liquidity	BCBS (2013) and Tirole (2011)
Tail risks	Acharya et al. (2011) and Gennaioli et al. (2013)		Countercyclical capital buffers	Drehmann and Gambacorta (2012)
Contagion				
Interbank claims	Allen and Gale (2000), Gai and Kapadia (2010) and Elliott et al. (2014)	Regulation tools		Allen and Gale (2007), Morris and Shin (2008) and Acharya and Oncu (2013)
Information contagion	Dasgupta (2004)			
Amplification	Kodres and Pritsker (2002) and Brunnermeier and Pedersen (2009)	Regulation tools		Goldstein and Leitner (2018) and Bouvard et al. (2015)
		Global measures	MES and SES	Brownlees and Engle (2017) and Acharya et al. (2017)
			SRISK	Acharya et al. (2012) and Brownlees and Engle (2017)
			ΔCoVaR	Adrian and Brunnermeier (2011)

In order to reduce systemic risks, Freixas et al. (2000) build a model to trace systemic risk in the interbank market. They research the insolvency contagion among financial institutions, and they investigate the problem-solving role of the central bank within the chain reaction. Lehar (2005) comes up with a measure to regulate risk which is correlation estimation among institutions' portfolios by using stock-market data, and he concludes that more profitable banks contribute less risk to the system. Huang et al. (2012) observe banks' marginal contribution to the system, and they conclude that an institution's systemic importance is approximately linear to its default probability, which creates another indicator for managers to regulate risk. Dang and Vong (2020) establish the EAGLES framework which derives the strategic response quotient (SRQ) from the computation of the interaction of four financial data components of income and costs, showing bank stability and profitability, and highlighting the risks associated with the market. Patro et al. (2013) propose that regulators should observe daily stock return correlations among firms to trail the changes of systemic risk. Cai et al. (2018) introduce an approach that is investment diversification, but this method overlooks the negative externality from other institutions. Many methods have been introduced in other papers, and regulators can refer to them according to their preferences.

With diverse approaches, systemic risks can be regulated effectively, and the purpose of regulation is to ensure that the whole financial system is stable, but not an institution individually. Acharya (2009) finds that when banks are regulated in isolation with capital requirements, their risks can be aggravated due to the negative externalities from others. Hu et al. (2012) bring up a network to manage risk by modelling and analysing, which involves business intelligence to simulate conditions for each bank with official data. Business intelligence takes each institution's systemic impact on the whole economy into consideration. Table 1 provides an outline of the main sources of systemic risks and the primary regulator tools as introduced in various previous literature. The more detailed descriptions of these tools as well as the pros and cons of each of them in practical applications will be provided in the following section.

3 Main sources of systemic risk and regulation tools

In the first part, we surveyed much theoretical literature and summarises three significant sources of systemic risk in the banking industry which are systemic risk-taking, contagion and amplification mechanisms. Corresponding regulation tools are displayed below, and more than one source may be combined in a bank certainly. Moreover, other compelling sources may be included subsequently in future research.

3.1 Systemic risk-taking

Acharya (2009) claims that most papers with 'systemic risk-taking' research why banks are willing to undertake similar risks and to be exposed to large risk exposures, enlarging amplification and contagion mechanisms. There are many forms of 'systemic risk-taking' mechanisms, including correlated investments, liquidity risks, and tail risks which are demonstrated below. For systemic incidents to occur, the risk exposure of banks should be correlated and large. In this section, correlated investments and liquidity risk will demonstrate the correlated risk exposure undertaken by banks, and tail risks will exhibit the significance of large risk exposures in this industry.

First, if banks engage in correlated investments, they are exposed to correlated risks, and even the same risks are undertaken by several banks. According to Acharya (2009), the bankruptcy of one bank lowers gross return rates on risky assets but increases these on the safe ones in equilibrium, squeezing the profits of these banks which are still working. This impact is known as 'recessionary spillover', which is a negative externality brought by the failed bank to the surviving ones. This phenomenon is interpreted by creditors as a signal that if a bank default, other banks may fail subsequently because their liquidation is connected and it will have a great effect on the whole banking industry (Acharya and Yorulmazer, 2008). When there is trouble, these banks who engage in the same portfolios and encounter the same risks cannot liquid their assets to help others and get financial support from others, because all of them are facing the same problem, and then the liquidation impact may spread to the entire economy and lead to a crisis. According to Onay and Öztaş (2018), banks use digital banking to manage their assets and liabilities actively, increase profitability to attract new clients and create a positive feedback loop. Due to COVID-19's impact, more banks convert their habits from physical mode to digital mode, and their investment in the same field 'digital finance' generates some potential risks (Maity et al., 2022).

When banks that are connected densely fail together, their liquidation of assets affects the whole market to a large degree, forcing the government to carry out a bailout because of the 'too-many-to-fail' assurance. This guarantee appears because if many banks go bankrupt simultaneously, then the whole financial system will be affected and disturbed badly which leads to panic in society, so governments have to bail these banks out to stabilise the market, and this process is at the taxpayers' expense. From government bailouts, banks can obtain maximised profits when a crisis comes. Farhi and Tirole (2012) claim that bailouts such as keeping the interest rate low are the preferred option when a large number of banks fail simultaneously. So, backed with a 'too-many-to-fail' guarantee, banks tend to invest in correlated and even the same assets, which is known as herding behaviour.

Secondly, liquidity risk is also a channel of systemic risk-taking mechanism that financial institutions are prone to undertake correlated risk exposure. According to Bhattacharya et al. (1985), banks engage in illiquid investments largely, resulting in the exposure to the risk of lacking liquidity in the whole banking system. The reason why banks tend to join in illiquid investments is a free-riding problem, based on which banks have motivations to invest a lot in illiquid assets for higher returns and ask other banks for liquidity when financial shocks come. A more detailed explanation for it is that if any banks anticipate a liquidity shortage, they would borrow from other banks with adequate liquid reserves, and then use the borrowed liquidation to fund the loan. So, when liquidity shocks occur, all banks engaging in illiquid investments unduly in equilibrium may default, and they are faced with correlated high risk, which will aggravate the financial shock.

Moreover, the imbalance between banks' assets and liabilities aggregates the hidden risk of liquidity. Facing with their relatively long-term debts, banks are offered a lower interest rate if they can pay the money back in a shorter period. The low charge of interest which means higher profits from funding attracts banks to over-rely on short-term debts. However, these debts are relatively dependent on market liquidity and carry comparatively high risks (Diamond and Rajan, 2001). When the market fluctuates, it is impossible to continue the capital flow within a short term, and the risk of cash flow interruption may easily occur, which could result in a liquidity crisis.

While correlated investments and liquidity risk demonstrate banks' risk exposure are correlated, this part will display how large the risk is. Tail risk, a kind of portfolio risk, occurs when the probability of investment moving more than three standard deviations from the mean exceeds what a normal distribution would reveal. In other words, tail risks arise when extreme cases occur, and it is a significant cause of contagion and amplification mechanisms in these extreme events.

Moreover, tail risks are highly correlated with the shadow banking system which is financial intermediaries creating credit across the international financial market, but it is not regulated under the supervision of any authorities. According to Acharya et al. (2011), the shadow banking system is used to coordinate tail risks because of its property of being unregulated. Besides the supervision benefits, shadow banking also takes advantage of the mispriced tail risks and amass assets which are especially susceptive to tail cases. Then, market investors are inherently biased against fair tail risk estimation, and they benefit from the regulatory arbitrage, so they may be unable to rationally restrain the financial institutions from such risk-taking. Furthermore, since the occurrence of a tail event is barely detected, theses market participants find it difficult to tell which financial institution adopts such a shadow banking system that deals with the tail risks. Thus, the shadow banking technology can become a cause of risk due to these participants' blindness to tail risks (Gennaioli et al., 2013).

Through literature review, there are many regulation tools to deal with systemic risk with a 'systemic risk-taking' mechanism. The most compelling reform internationally is the new Basel III rules, including a variety of tools to operate regulation (BCBS, 2011).

The first regulation tool is the capital ratio which is used to weaken risk-taking and systemic risk led by other sources generally. According to BCBS (2014b), higher capital ratios and stricter capital definitions are required for banks. For example, banks need to meet a minimum leverage ratio of 3% for their riskless assets to make sure they are relatively stable when facing a crisis (BCBS, 2014b). And the debt-to-capitalisation ratio is a kind of leverage ratio that is used to measure a bank's financial leverage.

$$\text{Debt-to-Capitalisation Ratio} = \frac{\text{Short-term Debt} + \text{Long-term Debt}}{\text{Short-term Debt} + \text{Long-term Debt} + \text{Shareholders' Equity}}$$

Regulators also require banks to keep a high capital ratio when they make loans to other parts of the economy, which restricts the banks with large risk exposure from lending money to others. Moreover, according to Ono et al. (2013), the upper limit for loan-to-value (LTV) ratio is used to regulate mortgage loans, restraining excessive lending and thus prohibiting the development of housing bubbles.

$$\text{LTV Ratio} = \frac{\text{Mortgage Amount}}{\text{Appraised Property Value}}$$

These capital requirements do reduce risk-taking and the targeted tools prevent banks from getting involved in similar investments to some extent. According to BCBS (2013), liquidity requirements are introduced to reduce the maturity imbalance among banks, and then restrict their needs from liquidation. In 2004, BCBS issued two liquidity requirements, liquidity coverage ratio (LCR) and net stable funding ratio (NSFR), in Basel III.

$$\text{LCR} = \frac{\text{High Quality Liquid Asset Amount (HQLA)}}{\text{Total Net Cash Flow Amount}}$$

The liquidity coverage ratio (LCR) requires banks to have enough reserves or assets which can be liquidated within a short period of time to fund themselves. When the crisis comes, banks should have the ability to liquidate their assets and help other institutions rather than rely on other banks, and if all banks depend on others for liquidation, then the liquid risk, a channel of the risk-taking mechanism of systemic risks, will appear.

$$\text{NSFR} = \frac{\text{Available Amount of Stable Funding}}{\text{Required Amount of Stable Funding}}$$

In addition, the cap on the short-term debt controlled by the net stable funding ratio (NSFR) is used to decrease funding liquidity risk (BCBS, 2014a). If banks over-rely on short-term debt, then they will not hold enough available amount of stable funding. So, when crises come, these institutions will look for short-term debt which is unstable and some of them cannot pay back on time when loans are mature, and then the liquidity risk may affect relevant banks and even the whole industry and economy. Moreover, Tirole (2011) suggests that liquidity should be monitored from a qualitative perspective but not from a quantitative viewpoint, otherwise liquidity regulation may be distorted.

Countercyclical capital buffers are the third regulation tool for systemic risk which is introduced in Basel III, and it is aimed at requiring banks to adjust their capital adequacy ratios (CAR) dynamically. Banks have the property of procyclicality which is a mutually reinforcing feedback mechanism. For example, banks lend to more creditors in boom times but shrink the size of the debt in recessions (Drehmann and Gambacorta, 2012). When in booms, banks increase their debts to make more profits but undertake more risks, and when in crisis, they deleverage which exacerbates the recession of the economy. Thus, procyclicality enables the banking industry to amplify the volatility of the business cycle and to cause or accelerate the instability of the financial system.

In order to control systemic risk caused by procyclicality, countercyclical capital buffers are brought up. And specific strategies are various and one example is that increase capital requirement in booms and reduce it in economy turndown times. For example, banks are often required to maintain a high capital-to-asset ratio when the economy performs well.

$$\text{Capital-to-Asset Ratio} = \frac{\text{Capital} + \text{Reserves}}{\text{Total Assets}}$$

In credit booming and systemic risk accumulation periods, countercyclical capital buffers need to be prepared to assure that financial institutions have enough capital to cope with the loss of economic downturn in the future, so as to enhance flexibility when they deal with external shocks, and decrease the likelihood of large-scale pressure appearing in the financial system (Repullo and Saurina Salas, 2011). Furthermore, excess countercyclical buffers can restrain banks' credit expansion in booms to some extent, and thus effectually prevent banks from enlarging losses in the crisis period. Thus, it can regulate systemic risk and establish a relatively safer banking system.

From the descriptions above, we know that the requirements for capital ratio, liquidity and countercyclical capital buffers from Basel Ⅲ are used to regulate systemic risk in the banking system, especially for the risk generated from the systemic risk-taking mechanism. These tools are specific and targeted, but they also have some shortcomings. In fact, Basel rules assume that banks diversify their investments to the maximum extent, but they are faced with a similar risk factor because they are engaged in a similar portfolio as we show above. In order to meet Basel's certain requirements, banks tend to behave similarly, which boosts the herding mechanism to some extent. So, there is a trade-off between making sure that all banks behave prudently and similarly to fulfill the requirements and promoting heterogeneous risk-taking (Wagner, 2010). Moreover, Allen et al. (2012) suggest that these requirements brought by Basel Ⅲ do restrict credit access and may decrease economic activities partly. For example, the countercyclical capital buffers impede excess debt growth. However, in general, these requirements for systemic risk regulation do standardise banks' operation and create a safer situation for themselves, investors and the whole banking industry.

3.2 Contagion

Contagion, another main source of systemic risk, happens when loss or failure in one bank spillover to other banks, resulting in loss propagation among the whole system. After exploring much literature, two main forms of such bilateral linkages which are interbank claims and information contagion are detected and their impacts on the stability of the banking system are presented below.

The first example of this linkage is interbank claims. When a crisis is coming and depositors want to withdraw their money, banks go to the interbank market to borrow money for liquidity, but most banks are not willing to lend money to others because they also need liquidity and they do not have enough confidence to ensure their money will be paid back. Without enough cash reserves and liquidity, default and risks then spread among the system through domino effects obviously.

Allen and Gale (2000) suggest that interbank markets concede risk-sharing that banks can join in the same investment positions and share risks, which decreases the probability of default in any bank in normal circumstances because they can help each other, acting as a trade-off strategy between default in the only one bank and contagion impact. This densely connected and complete framework where each pair of banks is connected directly is more stable than connected but incomplete ones because of risk-sharing (Freixas et al., 2000). In an interbank market, if each pair of banks has a direct correlation, then when risks appear, they can help each other directly. However, if some of them in the system rely on other banks through some intermediaries (banks), then when crises come, they need to take more steps to get financial aid which increases the risk of default. According to Gai and Kapadia (2010), because of risk-sharing, when a small shock happens, a densely correlated banking system can overcome it even if their connections are indirect. Nonetheless, when faced with a relatively large shock, all banks correlated with each other are more likely to fail simultaneously. Thus, risk-sharing can lead to high contagion risk when the shock is beyond a certain level.

Even encountering the contagion risk, most banks still choose to connect densely to form a network because of the maximised profits brought by integration and diversification. This means banks can rely on each other to form a whole unity, and a certain bank's liability can be taken charge of by the rest of the banks in this system (Elliott et al., 2014). By establishing bilateral links so as to help each other in liquidity crises, these banks are faced with raising contagion risk. In reality, if bank A is in liquidity trouble, then another bank will lend to bank A, resulting in its cash reserves decreasing and default risk increasing. Through sequential loans in this system, all banks have higher default risk, and they are more likely to be in liquidity trouble which generates contagion risk (a source of systemic risk).

The second form of bilateral linkages is information contagion. According to Chen (1999), believing that the returns of banks are related, depositors and investors will run to other banks if the run of a bank will have happened, resulting in a banking panic finally. This is because these banks hold similar assets and are exposed to related or even identical risks. Then, once bad information about one bank is released, people will suppose that other banks are also in trouble (Ahnert and Georg, 2018). Even if the bad news is not common for other banks and the shock caused by the first bank does not propagate to others, people also affirm it is a common shock and they are eager to withdraw their money, which raises a contagious run in the banking industry, and thus increases total systemic risk.

Similarly, Dasgupta (2004) showed that banks are so correlated through cross-deposits that negative news of one institution will propagate the whole banking system. In other words, if a depositor has two accounts in two respective banks and one of those banks is trapped in negative news such as liquidity shortage, then this customer may take money out of the two accounts simultaneously just in case, because he or she suspects these two institutions are correlated.

Moreover, contagion also exists among assets. If the liquidity of one asset falls, then that of other assets may decrease which is also caused by investors' expectations, and this phenomenon is known as the propagation mechanism. Even if these assets are not correlated to a large extent, investors tend to take cash out just to ensure their money is safe.

Based on our research, some radical regulation tools are carried out to tackle contagion. Allen and Gale (2007) show that when capital requirements are analysed to regulate risk, it should be based on their systemic significance which takes the interconnections among the banking system into consideration but not on the individual level, otherwise risk will be raised through the regulation. For instance, some system-weighted capital requirements can be adopted because this index considers how much impact an individual can have on the whole system.

In 2008, Bear Stearns, a large investment bank in the USA, went bankrupt due to run even if it met the capital requirements set by Basel regulation. According to Morris and Shin (2008), this is because the Basel items are set to limit banks' inherent riskiness but not systemic impact. In other words, with qualified capital requirements under the Basel approaches, banks can operate well in normal market circumstances, but they cannot be guaranteed to be safe when a crisis comes as a result of systemic impact brought by other institutions in this system. For example, if a bank can generate great profits from some investments with low risk, but it would have a large impact on the whole banking system and bring high risk into this market, then this investment should be regulated or even prohibited. Morris and Shin (2008) claim that the difference between an asset's riskiness and its systemic importance should be distinguished. Even if its own risk level is low, sometimes, it can affect other institutions to a large degree. Thus, capital requirements should be regulated based on the whole system but not only on the individual bank, otherwise, it may lead to overlooking some risks and provide some potential causes for crises' formation and development.

In order to ensure that banks can survive crises and can be stable as a whole, the original capital requirements aimed at measuring each individual's risk are not enough and the regulatory authorities should also take spillover effects among these financial institutions into consideration. Drehmann and Tarashev (2011) introduce two measures to consider a bank's systemic importance. The first one records the ability of a financial institution to spread a shock, while the other one considers its susceptibility to shocks caused by the rest firms in this system. They divide the measure of systemic risk into two parts, which simplifies the risk regulation process and makes it more logical.

From a more radical perspective, regulators should analyse which assets and liabilities have a systemic effect, rather than concentrating on the individual bank, based on which regulation managers can bring up policies to limit the use of specific products for certain banks to achieve systemic risk regulation (Acharya and Oncu, 2013). As we said in the 'systemic risk-taking' part, banks tend to join in the same position of the same investment of specific assets, so they are correlated and risks among them are contagious. Once these assets are in trouble, many banks will be involved, and then systemic risks will show up. In order to control this kind of systemic risk generated from contagion, banks' assets and liabilities need to be regulated carefully.

3.3 Amplification

The self-reinforcing nature of liquidity crises can explain well why small shocks can result in considerable effects on the whole system. When market prices fall, banks tend to sell their assets for liquidation to achieve funding requirements, which enlarges the pricing downturn, resulting in further sales. As for financiers, in a negative liquidity crisis, many of them sell their securities, and only the most inexperienced market players will be willing to pay a low price for it. Moreover, if investors suffer losses on one investment, then they will decrease their positions on the other assets, which leads to market prices dropping, indicating more losses in the future (Kodres and Pritsker, 2002). Furthermore, when participants trade less and the market becomes less liquid, institutions tend to charge higher margin requirements for their own profits, which puts more pressure on investors (Brunnermeier and Pedersen, 2009). These snowball effects driven by liquidity crises amplify a certain scale of a shock to a large and complicated effect on many institutions simultaneously, raising systemic risk in the banking system.

To deal with amplification mechanisms, stress tests are introduced which can help regulators know how fragile banks are and how much capital they can achieve during the crisis, which is useful for authorities' regulation. The disclosed information about stress tests can help investors to distinguish each bank's financial condition and increase symmetric information and transparency. According to Goldstein and Leitner (2018), publicising the results of stress tests can decrease the chances of risk-sharing among banks. Specifically speaking, the unqualified banks which fail to pass the tests will be excluded from risk sharing, which reduces systemic risks to some extent. Bouvard et al. (2015) also claim that disclosure of news and data about institutions in the banking system can prevent runs during crises as a result of baseless panic, because most investors are symmetrically and well informed about banks' positions, and then they will not withdraw money blindly.

However, by using the same tool, stress tests, banks can also be more concentrated on the balance among runs (Dala et al., 2020). In this case, banks have the incentive to hide information that could be harmful to their images just for attracting more funding. They disclose beneficial economic fundamentals and conceal some bad data, which creates an illusion for investors that they are well performed. These problems impede the proper implementation of such disclosure policies because they may generate excess opacity which raises the probability of the occurrence of systemic crises.

4 Global measures

There are some measures for systemic risk regulation in the banking system which are not targeted at specific sources and exact forms of systemic risk. As global measures, they are used to regulate systemic risks without identifying the source and channel of risks. Compared to the regulation tools above targeted at specific sources of systemic risk which use supervisory data, global measures using market data can be computed at any time, and they can catch sudden variations in systemic risk regimes. This is because if markets are efficient, then such information will be reflected in the market data, with which systemic risk can be measured reasonably and then regulated effectively. So far, three measures have been chosen and will be described below, which are the marginal expected shortfall (MES) and the systemic expected shortfall (SES), SRISK and ΔCoVaR. Other global measures may also be compelling and they will be discussed if they are investigated to be significant enough in later research.

4.1 MES and SES

Marginal expected shortfall (MES) and systemic expected shortfall (SES) are both measured by expected shortfall (ES). According to Brownlees and Engle (2017), MES is defined to measure the increment of the risk of the whole system caused by the increment of the weight (w_{it}) of a specific bank in the banking system. SES can be interpreted as a systemic risk which is contributed to the system by an individual bank (Acharya et al., 2017).

$$\mathrm{MES}_{it} = \frac{\partial \mathrm{ES}_{market}}{\partial w_{it}} = \beta_{it}\,\mathrm{ES}_{market}$$

Here, MES_{it} represents the MES of the i^{th} bank at time t. Before computing MES, market betas need to be known. Beta is a measure of an asset's volatility in relation to the overall market, and it is used to measure systematic risk. For a specific institution, its MES equals the product of its beta and the system ES, so it raises when its beta goes up due to system ES being a positive constant for every institution at a given time. However, system ES will change with time passing, so we cannot only use betas (systematic risk) to estimate systemic risk evolution. After computing MES for each bank, their figures can be ranked from the largest to the smallest, representing their systemic contribution to the system decreasing. And it should be noted that given a certain time, the systemic risk rating of banks according to MES is the same as that based on market betas. Then, the banks which contribute risk largely to the banking system should be regulated with specific policies and strategies to reduce their systemic risk.

4.2 SRISK

Acharya et al. (2012) defined SRISK (systemic risk measure) as the expected capital shortfall of a specific bank, given the condition of a crisis influencing the whole system.

$$\mathrm{SRISK}_{it} = \max\left\{0, \underbrace{k\left(D_{it} + (1 - LRMES_{it})W_{it}\right)}_{\text{Required capital}} - \underbrace{(1 - LRMES_{it})W_{it}}_{\text{Available capital}}\right\}$$

where k is the prudential capital ratio, D_{it} is the book value of total liabilities, $LRMES_{it}$ is the long-run MES, and W_{it} is the market capitalisation.

It is computed as the maximum value of 0 and the difference between required capital and available capital (the difference should be that required capital minus available capital, and no absolute values). The larger value of the difference means a larger shortfall and a higher probability to default and be in trouble, indicating the bank has higher risks. From this viewpoint, the bank with a higher value of SRISK contributes more risk to the whole banking system, implying the specific bank possesses higher systemic risk. As we rank institutions based on their MES above, we can also rank them according to their SRISK statistics from the largest to the smallest, and then regulate the banks with high SRISK specifically.

Compared with MES and SES, SRISK takes the liabilities and sizes of banks into consideration (Brownlees and Engle, 2017). SRISK increases with leverage raising, so, when banks use more leverage, they are required to hold more capital reserves, which causes SRISK to go up. In order to keep SRISK constant, banks need to hold more reserves to ensure their systemic impact on this industry is unchanged. Furthermore, interconnections among banks are also involved in SRISK, such as MES. The interconnections between an institution and the rest are measured by long-run marginal expected shortfall (LRMES) which is an element considered in SRISK computing. LRMES shows how a specific firm responds to market fluctuations over a long period, and it can be computed through its daily MES. So, SRISK also considers market betas which are involved in MES, but unlike MES, ranking according to SRISK is not the same as that according to betas, because it does not only rely on betas but also depends on liabilities and market capitalisation.

4.3 ΔCoVaR

By definition, delta conditional value-at-risk (ΔCoVaR) is the different values of value-at-risk (VaRs) of the banking system between the conditions given that a specific bank is in distress and in the median state respectively.

$$\Delta CoVaR_{it} = CoVaR_{it}\left(conditional\ on\ r_{it} = VaR_{it}\right) \\ -CoVaR_{it}\left(conditional\ on\ r_{it} = Median\left(r_{it}\right)\right)$$

where r_{it} is the return of the i^{th} bank at time t, and VaR is the value-at-risk of the specific bank. It is targeted at measuring the systemic risk contributed to the whole system by an institution. The larger the difference between the two states indicates the higher risk the bank contributes to the market, so it is obvious that a larger value of this index suggests a higher systemic risk of such a firm. Values of this statistic of banks can be obtained by the computation from relevant data of each institution, based on which regulation can be executed.

According to Benoit et al. (2013), given a specific bank, if its marginal return is symmetrically distributed near zero, then,

$$\Delta CoVaR_{it} = \gamma_{it} VaR_{it}$$

its ΔCoVaR is proportional to its VaR which measures tail risk. And the relevant coefficient γ (the value of proportion) is different for each institution, suggesting a bank with the highest tail risk may be not the one with the largest systemic risk (Adrian and Brunnermeier, 2011). So, comparing the VaRs of financial institutions cannot tell how their systemic risks rank. Nonetheless, when the variance-covariance matrix is consistent for a certain bank, then its coefficient will not change with time passing (Adrian and Brunnermeier, 2011). In this case, it is also proved that for a certain institution, measuring its ΔCoVaR (contributed systemic risk) is the same as forecasting its VaR (tail risk) in isolation.

5 Evaluation and comparison of two main approaches

Based on the description above, the differences are clear between the regulation tools used to deal with specific sources of systemic risk and global measures aimed at tackling systemic risk without identifying which source of risk and transmission leads to systemic contribution.

The former ones usually depend on some qualitative models, and they focus on what induces systemic risks and propose the regulation tools with the purpose of addressing the specific source, which is more specialised and will have an accurate impact on systemic risk regulation. These tools can capture certain aspects of systemic risks, and when we use them simultaneously, risk can be shown logically and thoroughly. And each tool possesses its own advantages. For example, Basel III solves the problem of the fragmented regulatory authorities, which enhances global coordination and reduces the probability of contagion (Dell'Ariccia and Marquez, 2006). In addition to their superiorities, these source-specific approaches also have inferiorities. These measures are computed by confidential data which is disclosed quarterly or even annually. The publicised data is lagged and may be outdated when market participants want to know the current situation of a specific institution. Moreover, these specific tools are complex and difficult to apply when facing a situation where several sources of systemic risk are all involved in a bank or even some diverse transmissions of form are hard to identify.

On the contrary, global measures are used to detect systemic contributions with public market data. These data are up-to-date and investors can compute favourable statistics and obtain the current situation of each institution easily, which is very convenient for them to choose which bank deserves an investment. Furthermore, these measures can be used more generally, and risks can be measured and regulated without the effort to determine their sources and forms. When more than two sources of systemic risk appear, global measures can be used for simplicity. Nonetheless, one drawback of global measures is that they cannot encompass all sources and aspects of systemic risk, which should be paid attention to when using them. It seems that the best global measures included in this survey, MES, SRISK and ΔCoVaR, can only capture certain variations in the market, but it is not that enough. For instance, Zhou et al. (2020) find that MES and ΔCoVaR of banks in China rise aberrantly during 2008 global financial crisis, while SRISK grows steadily from 2007 to 2018 which reflects the improvement of the economy in China. Even if different measures consider different facets of systemic risk in the banking industry, the rankings of financial institutions' systemic importance with diverse metrics have a strong correlation with each other (Huang et al., 2019).

While these two types of approaches both have merits, it is not adequate to use only one kind of measure to regulate systemic risk in the banking system. We need to build more connections and establish the integration between these two parts. With more new measures appearing, regulators need to understand more quickly and thoroughly how these measures interact with each other and complement each other. They should not only focus on the isolated causes and transmissions of systemic risk but also need to jump out of the circle to have a general overlook of the systemic risk. Similarly, it seems perilous for them to regulate systemic risk merely according to global measures without a legible identification of the risks they catch and those they may ignore, because the best global measures nowadays we present above are still not sufficient enough to measure and identify systemic risk from all aspects. Kleinow et al. (2017) claim that the systemic risk of a financial institution is estimated to be different when using different measures, so regulators should be careful when they use only one measure to compute a bank's systemic impact on the system. Benoit et al. (2013) also show a similar conclusion that various measures determine different systemically important financial institutions (SIFIs).

6 Conclusions

This survey discusses where the systemic risks come from and how to regulate them with which kind of measures. Nowadays, although the sources of systemic risks are better identified and the regulation becomes more normative, there are many things left to be done, and more effective measures should be developed. This survey only summarises the most important sources and part of tools, and explains how they work with advantages and disadvantages.

First, this survey demonstrates the three sources of systemic risk in the banking industry, including systemic risk- taking, contagion and amplification mechanisms. For the first source, systemic risk-taking, three forms of transmission are involved which are correlated investments, liquidity risks and tail risks. And regulators can refer to Basel III rules and use its requirements, including the capital ratio, liquidity requirements and countercyclical capital buffers, to regulate banks' systemic impact on the economy. As for the second source, contagion mechanism, its two channels are interbank claims and information contagion, and managers can tackle this kind of systemic risk with some system-weighted capital requirements. Next, the amplification mechanism is mainly generated from the self-reinforcing property of liquidity crises. In order to prevent such an event from happening, all banks should be stress-tested, and the disclosed result can impede amplification to some extent. In the main second part of 'Methodology and methods', global measures are introduced to regulate systemic risk without classifying the type of such a risk. They use market data for convenience, which is totally different from the targeted regulation tools demonstrated above which use supervisory data. This part includes three measures which are MES and SES, SRISK and ΔCoVaR. The next part is to evaluate and compare the two kinds of approaches in the first two parts. They both have strengths and weaknesses, so they need to be complemented each other when regulation is implemented. In summary, more linkage and integration between them should be established to monitor risks effectively. Some measures which are targeted at specific sources nowadays may be developed into global measures working for more aspects of systemic risk in the future.

Measures are important for policymakers when they need to monitor risks and quantify the spillover effect caused by some banks in the whole system. Several regulation measures are explained above, which regulators can choose based on their own needs and requirements. What policymakers need to pay attention to is how to integrate these measures and their policies optimally to ensure each firm's systemic importance is well controlled. They need to implement suitable and powerful policies which are suitable for all institutions in this system to achieve their goals. And managers need to consider financial institutions' systemic importance rather than focus only on their own risk in isolation. Although risk regulation tools are limited nowadays, more measures will be carried out in the future, since more data will be publicised more frequently with better quality (Cerutti et al., 2014). With more effort, more advanced technology and experience from past financial events, systemic risks can be regulated better and the banking industry can be guaranteed to be stable and energetic to a large extent.

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