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SYSTEMIC RISK, MONETARY POLICY AND PORTFOLIO DIVERSIFICATION IN THE GREAT CRISES' ERA

edited by
VINCENZO PACELLI and IDA CLAUDIA PANETTA

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SYSTEMIC RISK, MONETARY POLICY AND PORTFOLIO DIVERSIFICATION IN THE GREAT CRISES’ ERA

edited by

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Systemic Risk, Monetary Policy and Portfolio Diversification in the Great Crises' Era

VINCENZO PACELLI and IDA CLAUDIA PANETTA
Introduction

VINCENZO PACELLI
Systemic Risk and Network Science

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Vincenzo Pacelli and Ida Claudia Panetta

INTRODUCTION

The crises of the last fifteen years have underlined how much the financial system is today more exposed and vulnerable to systemic risk, defined as the risk of uncontrolled propagation of a crisis of a single player or area of an economic system to the entire system. Systemic risk is more relevant today than in the past due to the increasing interconnection between the players in the financial system and the increasing speed of flows of goods, money and man. All this prompts us to reflect on the need to holistically analyse, predict and manage systemic risk through logical-conceptual schemes that can be borrowed from the Science of Networks.

The main objective of this volume is to investigate the evolution of systemic risk: from identifying its components (characteristics) to its measurement and the tools to mitigate it. As we have just said, the concept of systemic risk has become central to the economic policy debate following the various financial crises that have occurred in recent years. These events have stimulated the development of international literature to measure and regulate systemic risk. The book sheds light on the role played by the European Central Bank (ECB) in limiting and managing banking contagion between countries (e.g. credit risk), which plays a crucial role in the current context of high uncertainty (COVID-19 and the Russia-Ukraine war). It is important to recall that Lehman Bros' default showed how much the choices of a single entity (financial firm, state) could influence those of other financial systems.

This volume contains several groundbreaking contributions dedicated to (*i*) identifying the multidimensionality of systemic risk, (*ii*) understanding how the use of network science may help deepen the knowledge of systemic risk, *(iii)* visualising how monetary policy interventions have affected contagion risk, and (*iv*) highlighting how asset allocation strategies can be a proper systemic risk management tool, especially in the alternative finance context. Each of the six essays tackles one of these goals by proposing different points of view in approaching the study and solving some concrete issues posed by the turbulent recent *Great Crises Era*. This collection of essays starts by defining systemic risk throughout its multifaceted shape, proposing to look at the so complex phenomenon by borrowing logical-conceptual schemes from network science. The bibliometric literature review run on the topic revealed that this strand of studies appears promising and still young and that further in-depth studies are needed. In addition, the collection contains interesting empirical results that highlight how ECB policies have played a key role in managing the spread of systemic risk across Eurozone countries. Furthermore, it is possible to find shreds of evidence in diversification portfolio strategies to grasp the most from different (alternative) asset classes to *pass-through* these periods of financial turbulence.

This volume represents the first reflection on a theme that we consider central and that we will continue to deepen, and it is aimed to provide food for thought for researchers and academic practitioners in the field of systemic risk measurement and management, specialists in banks and financial institutions, policymakers and students of economics and finance. We want to thank all authors for their contributions and anonymous referees for their thorough analysis and helpful comments.

Vincenzo Pacelli

SYSTEMIC RISK AND NETWORK SCIENCE[*†]

ABSTRACT

Le crisi degli ultimi quindici anni hanno evidenziato quanto il sistema finanziario sia oggi quanto mai esposto e vulnerabile al rischio sistemico, inteso come il rischio di propagazione incontrollata di una crisi di un singolo attore o area di un sistema economico all'intero sistema. Il rischio sistemico è oggi inoltre molto più rilevante rispetto al passato in ragione della sempre più elevata interconnessione fra gli attori del sistema economico e della sempre maggiore velocità di circolazione delle merci, della moneta e dell'uomo. Tutto ciò spinge a riflettere sulla necessità di analizzare, prevedere e gestire il rischio sistemico in chiave olistica e attraverso gli schemi logico-concettuali mutuabili dalla scienza delle reti.

The crises of the last fifteen years have underlined how much the financial system is today more exposed and vulnerable to systemic risk, defined as the risk of uncontrolled propagation of a crisis of a single player or area of an economic system to the entire system. Systemic risk is more relevant today than in the past due to the increasing interconnection between the players in the economic system and the increasing speed of flows of goods, money and man. All this prompts us to reflect on the need to analyse, predict and manage systemic risk holistically and through the logical-conceptual schemes that can be borrowed from the Science of Networks.

KEYWORD

Rischio sistemico – scienza delle reti – crisi finanziaria

Systemic risk – network science – financial crisis

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SUMMARY: 1. Introduction. – 2. Systemic risk: definition, causes and propagation mechanisms. – 3. The necessary combination of systemic risk analysis and network science. – 4. Reflections.

1. The sub-prime mortgage crisis broken out in 2007 in the USA, the subsequent - and in some ways consequent - sovereign debt crisis in Europe and today the pandemic and the Chinese debt crisis have highlighted, within fifteen years, how the financial system is today more exposed and vulnerable to the risk of contagion, or systemic risk, defined as the risk of uncontrolled propagation of a crisis of a single player or area of the economic system to the entire system. Systemic risk is also much more relevant today than in the past, due to the increasing interconnection between the players in the economic system and the increasing speed of flows of goods, money and man. Just as, from a health point of view, the transmission of a virus is closely linked to the relationships between individuals and the speed of their flow, the same can be said for the transmission of a financial crisis. We could, in other words, note how the genesis and evolution of the crises of the last fifteen years have highlighted the relevance and danger of systemic risk and the need to analyse and manage it through logical-conceptual schemes borrowed from the Science of Network.

The evolution and rapid global spread of the 2007-2008 financial crisis have also highlighted, among other things, the limits of the architecture of regulation and control in the financial sector, suggesting a broadening of the spectrum of analysis from a merely micro-prudential perspective to a macroprudential one, which adequately takes into account the complex networks of relationships that characterize financial systems. Until the outbreak of the great financial crisis, international financial regulation and supervision were disproportionately oriented toward individual intermediaries and players in the financial system and ignored the interconnections between them. As mentioned, the events of the last fifteen years have highlighted the relevance and the danger of systemic risk, reflexively inducing the international supervisory authorities to a sudden, radical and opportune widening of their spectrum of analysis, or from the conditions of solidity and solvency of the single actor to the overall stability of the entire economic system.

In this essay, we investigate the need to analyse the complex phenomenon of systemic risk in a holistic way and through logical-conceptual schemes borrowed from network science. To support this thesis, in the next paragraph we will outline the causes and propagation mechanisms of systemic risk, while in the third paragraph we will deepen the logical-conceptual paradigms that make network science a fundamental tool for understanding and analysing systemic risk, and then conclude in the fourth paragraph with some reflections on the current economic situation.

2. Although it is not easy to attribute an unambiguous and exhaustive definition to «systemic risk» due to its complexity and multidimensionality as well as its many causes and varied facets, nevertheless, wishing to circumscribe the perimeter of the discussion, it is possible to affirm that for systemic risk is defined as the risk that the crisis, bankruptcy or the mere perception by the market of the risk of insolvency of one or more relevant players in an economic system - essentially large companies, financial intermediaries or States - may lead to generalized crises, insolvency or chain failures of other players in the economic system. The systemic risk, in other words, is, therefore, the risk associated with the manifestation of an event capable of causing, through propagation and contagion mechanisms, structural effects and therefore a situation of systemic and generalized instability. From what has been highlighted above and as will be deepened in the continuation of the discussion, the systemic risk appears to be multidimensional and extremely complex in that its origin lies in multiple phenomena and dynamics that are significantly interconnected, while its propagation is influenced by the various forms of interaction and interconnection between the various players in an economic system.

As well illustrated by the International Monetary Fund[3], systemic risk tends to manifest itself through sequential events that start from one or more shocks of various nature that then propagate in the economic system with a chain effect generating a crisis of systemic nature. Systemic risk must be defined as typically endogenous to the financial system, not only because it derives from the collective behaviour of economic agents whose choices may be rational at an individual level, but harmful to the financial system as a whole, but above all because it tends to feed on itself, to accumulate over time and then spread, in an uncontrolled way, throughout the financial system when a shock occurs.

In the light of the above, to deepen and understand the complex nature of this particular type of risk, it is, therefore, necessary to examine the possible triggers and mechanisms of propagation of systemic risk.

First of all, it is well to clarify that when talking about triggers, it is necessary to distinguish between the initial shocks that give rise to the mechanisms for propagating the crisis and the causes that feed and favour these propagation mechanisms.

A shock can be defined as any event that can significantly or structurally modify or transform a financial system, limiting or even inhibiting its ability to carry out its specific functions. There are many shocks capable of generating mechanisms for the

[3] See M.N.R. Blancher, M.S. Mitra, M.H. Morsy, M.A. Otani, T. Severo, M.L. Valderrama, *Systemic Risk Monitoring («SysMo») Toolkit – A user Guide*, in *International Monetary Fund*, 13/68, 2013.

systemic propagation of a financial crisis, but they can be classified, at the cost of some simplification of a taxonomic nature and some overlapping, in four closely linked categories:

i. sudden increase not justified by a phase of economic expansion of the cost of money, which incentivizes the phenomena of moral hazard and adverse selection[4,5];

ii. incorrect or short-sighted economic, social and fiscal policies that lead to imbalances in public accounts, trade and balance of payments, or that inhibit a country's growth, lending itself to speculative attacks on sovereign debt[6,7,8];

iii. crisis, bankruptcy, or mere market perception of the risk of default of a financial intermediary, sovereign state, or industrial firm characterized by significant size and significant economic and financial correlations[9,10,11,12,13,14,15,16];

iv. idiosyncratic, exogenous events of varying nature and origin that lead to an abrupt contraction of demand or supply in certain markets, reflexively causing the sudden reduction of prices of real and financial assets and, in particular, the collapse of the value of the residential or commercial real estate [17,18].

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[4] See D. Delli Gatti, *La crisi dei mutui subprime*, in *Osservatorio bancario*, 1, 2008, pp. 28-58.

[5] See T.F. Rötheli, *Causes of the financial crisis: risk misperception, policy mistakes, and bank's bounded rationality*, in *The Journal of Socio-Economics*, 39(2), 2010, pp. 119-126.

[6] See V. Pacelli, *Consulenza finanziaria e ottimizzazione di portafoglio. Come gestire la relazione con l'investitore in tempo di crisi*, in *Bancaria editrice*, vol. 124, 2014.

[7] See F. Eser, B. Schwaab, *Evaluating the impact of unconventional monetary policy measures: Empirical evidence from the ECB′ s Securities Markets Programme*, in *Journal of Financial Economics*, 119(1), 2016, pp. 147-167.

[8] See M.S. Pagano, J. Sedunov, *A comprehensive approach to measuring the relation between systemic risk exposure and sovereign debt*, in *Journal of Financial Stability*, 23, 2016, pp. 62-78.

[9] See F. Allen, D. Gale, *Financial contagion*, in *Journal of political economy*, 108(1), 2000, pp. 1-33.

[10] See X. Freixas, B.M. Parigi, J.C. Rochet, *Systemic risk, interbank relations, and liquidity provision by the central bank*, in *Journal of money, credit and banking*, 2000, pp. 611-638.

[11] See J. Beirne, M. Fratzscher, *The pricing of sovereign risk and contagion during the European sovereign debt crisis*, in *Journal of International Money and Finance*, 34, 2013, pp. 60-82.

[12] See S.C. Nelson, P. J. Katzenstein, *Uncertainty, risk, and the financial crisis of 2008*, in *International Organization*, 68(2), 2014, pp. 361-392.

[13] See A. Michaelides, A. Milidonis, G.P. Nishiotis, P. Papakyriakou, *The adverse effects of systematic leakage ahead of official sovereign debt rating* announcements, in *Journal of Financial Economics*, 116(3), 2015, pp. 526-547.

[14] See D. Cronin, T.J. Flavin, L. Sheenan, *Contagion in Eurozone sovereign bond markets? The good, the bad and the* ugly, in *Economics Letters*, 143, 2016, pp. 5-8.

[15] See P. Engler, C.G. Steffen, *Sovereign risk, interbank freezes, and aggregate* fluctuations, in *European Economic Review*, 87, 2016, pp. 34-61.

[16] See M.S. Pagano, J. Sedunov, *A comprehensive approach to measuring the relation between systemic risk exposure and sovereign debt*, in *Journal of financial Stability*, 23, 2016, pp.62-78.

[17] See C.M. Reinhart, K. S. Rogoff, *Banking crises: an equal opportunity menace*, in *Journal of Banking & Finance*, 37(11), 2013, pp. 4557-4573.

[18] See T.F. Rötheli, *Causes of the financial crisis: risk misperception, policy mistakes, and bank's bounded rationality*, in *The Journal of Socio-Economics*, 39(2), 2010, pp. 119-126.

Listed the mainshocks that can give rise to the systemic propagation process of a crisis, it is then necessary to dwell upon the causes that favour and feed these propagation mechanisms. So, how does a shock become systemic? The causes that determine the propagation of an initial shock, through the mechanisms that we will examine later, to an entire economic system are essentially the following:

(a) crisis of confidence, uncertainty and information asymmetries in financial markets[19,20,21];

(b) high indebtedness of players in the economic system and thus high financial dependence of debtors on creditors and vice versa, which makes the whole system vulnerable in times of crisis[22];

(c) high interconnectedness between the main players in the economic and financial system, in particular high exposure of banks to sovereign debt and interbank markets [23,24,25,20,26];

(d) microeconomic causes such as, for example, gaps in financial regulation in some countries, limitations in prediction and risk management techniques, deficiencies in asset valuation models or international accounting systems[27,28,11,29].

In particular, the empirical evidence of the main international financial crises confirms how it is precisely the high level of interconnection between the main players in the economic and financial system that is the main factor that feeds the mechanisms for the propagation of a systemic crisis. The genesis and subsequent evolution of the U.S. financial crisis characterized by over-indebtedness, initial low-

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[19] See C. Cottarelli, L. Forni, J. Gottschalk, P. Mauro, *Default in today's advanced economies: unnecessary, undesirable, and unlikely*, in *IMF Staff Position Notes*, 2010 (012), 2010.

[20] See M.J. Flannery, S.H. Kwan, M. Nimalendran, *The 2007–2009 financial crisis and bank opaqueness*, in *Journal of Financial Intermediation*, 22(1), 2013, pp. 55-84.

[21] See F. Duarte, T.M. Eisenbach, *Fire-Sale Spillovers and Systemic* Risk, in The *Journal of Finance*, 76(3), 2021, pp. 1251-1294.

[22] See M.K. Brunnermeier, L. Garicano, P.R. Lane, M. Pagano, R. Reis, T. Santos, D. Thesmar, S. Van Nieuwerburgh, D. Vayanos, *The sovereign-bank diabolic loop and ESBies*, in *American Economic Review*, 106(5), 2016, pp. 508-12.

[23] See A. Blundell-Wignall, *Solving the financial and sovereign debt crisis in* Europe, in *OECD Journal: Financial Market Trends,* 2011(2), 2012, pp. 201-224.

[24] See F. Brutti, P. Sauré, *Transmission of sovereign risk in the euro crisis*, in *Journal of International Economics*, 97(2), 2015, pp. 231-248.

[25] See H. Hoque, D. Andriosopoulos, K. Andriosopoulos, R. Douady, *Bank regulation, risk and return: Evidence from the credit and sovereign debt* crises, in *Journal of banking & finance*, 50, 2015, pp. 455-474.

[26] See H. Böhm, S. Eichler, *Avoiding the fall into the loop: Isolating the transmission of bank-to-sovereign distress in the Euro Area*, in *Journal of Financial Stability*, 51(100763), 2020.

[27] See V. Pacelli, *Consulenza finanziaria e ottimizzazione di portafoglio. Come gestire la relazione con l'investitore in tempo di crisi*, in *Bancaria editrice*, vol. 124, 2014.

[28] See C.E. Gonçalves, B. Guimaraes, *Sovereign default risk and commitment for fiscal adjustment*, in *Journal of International Economics*, 95(1), 2015, pp. 68-82.

[29] See F. Eser, B. Schwaab, *Evaluating the impact of unconventional monetary policy measures: Empirical evidence from the ECB′ s Securities Markets Programme*, in *Journal of Financial Economics*, 119(1), 2016, pp. 147-167.

interest rates, uncontrolled development of financial engineering, ineffective controls by the competent authorities, opportunistic behaviour of various players and speculative bubbles in various markets are too well known to dwell further. The US subprime mortgage crisis of 2007 thus became systemic due to the interconnection between international economic and financial systems and spread throughout the world and in particular to weaker areas, just like a virus that attacks and does greater damage to weaker subjects with lower immune defences. This is what has happened in Europe since 2008 that is international financial speculation has taken advantage of imbalances in public finances and the balance of trade and payments of some European countries (PIIGS) (Portugal, Italy, Ireland, Greece and Spain), of the absence of a European political union capable of supporting monetary union and therefore of a weak political and economic governance at the community level with limited powers, which has therefore detected inadequate to prevent and deal with the crisis. In recent months, there has been great concern about the sustainability of the Chinese economy's debt, which risks producing significant systemic effects in the event of deflagration due to the abnormal size of China's public and private debt[30] and due to speculative bubbles in the real estate sector, which expose the main Chinese real estate companies (Country Garden, Poly, Evergrande, Vanke and Sunac) to the risk of default. The current crisis in the Chinese real estate sector or the crisis of sovereign debt in Europe in 2009 can certainly be considered, therefore, as consequences of the systemic nature of the US crisis of 2007, but it is equally true that all these crises were favoured by evident errors in economic policy.

After describing the possible initial shocks and the causes that can feed the systemic propagation of these shocks to an entire economic system, it is now necessary to deepen the mechanisms and methods of transmission and propagation of a systemic crisis. In this regard, Aharony et al.[31] underline the existence of two channels for the propagation of shocks: the «direct exposure channel» and the «information channel», which can act independently but also jointly. While the direct exposure channel refers to the domino effects that can occur due to the significant interconnections present within the interbank market or due to the

[30] As of March 2021, China's aggregate household, corporate and public sector debt exceeded $46 trillion, or 287% of China's annual GDP. While at the beginning of the century China accounted for a fairly small share (less than 3%) of global non-financial sector debt (public and private), its weight is currently 21%, second only to that of the United States (28%). To understand, in particular, the enormous leverage of the Chinese construction sector, it is sufficient to consider that at the end of 2020 the top 5 Chinese real estate companies (Country Garden, Poly, Evergrande, Vanke and Sunac) had total liabilities (excluding «off-balance sheet» liabilities) of over $1 trillion, which is about 10 times more than 2011 levels.

[31] See J. Aharony, A. Saunders, I. Swary, *The effects of a shift in monetary policy regime on the profitability and risk of commercial banks*, in *Journal of monetary economics*, 17(3), 1986, pp. 363-377.

sovereign exposures held by the banking system; the information channel reconnects to information asymmetries or errors in the interpretation of signals by market participants and savers, who are imperfectly informed respect to the nature of the shock that can be the idiosyncratic or diffuse origin[32]. As argued above, following a shock to the economy, first of all, the ability of borrowers to repay loans is reduced. Thus, the first effect of the shock is represented by a reduction in the value of banks' capital assets, and this reduction will be more pronounced the greater the percentage of assets recorded at market value on banks' balance sheets. To secure their balance sheets and preserve their capital and financial solidity, as highlighted above, banks react to these shocks by rationing credit and activating strategies of deleveraging and asset sales, which fuel the process of falling prices of financial and real assets in the markets and thus the deflationary spiral that, also due to the reduction in the values of bank assets and assets in general available in the markets as collateral, further fuels the vicious circle of credit rationing, the collapse of investment and industrial production, the reduction in tax revenues and the increase in public debt, with consequent difficulties in refinancing on the markets and increased speculative pressures on the cost of debt issued by a government, whose solvency may even be compromised in the most serious cases, leading to chain effects on the balance sheets of banks holding sovereign debt. It can therefore be seen how, in case of the occurrence of an event capable of fuelling the propagation mechanisms of a systemic crisis, a bank's defence strategies can determine, in the absence of concerted and efficient monetary and fiscal policies, perverse effects that end to fuel the deflationary spiral and further undermining the economic and capital balances of the economic system concerned. And all these risks feed through both the channel of direct exposure of banks' balance sheets and through the information channel, since the investment or disinvestment choices of institutional investors, such as banks, condition the choices of other operators in the markets.

3. Today we live in a globalized, complex and significantly interconnected world, in which complex systems and phenomena, apparently distant from each other, in reality, influence each other. This reality exposes societies to systemic risks and requires analysis through a holistic approach to phenomena under different disciplines, to investigate, through the help of network science, hidden relationships between economic, financial, political, health and environmental phenomena. In other words, today nothing happens in isolation. Quoting Barabasi[33] (2004), phenomena and events are connected with countless others in a huge and complex universal puzzle, in which these phenomena and events cause each other and interact with each other. We, therefore, live in a «small world», in which everything is

[32] See A. Di Clemente (a cura di), *Rischio sistemico e intermediari bancari*, in A. Di Clemente, *Stabilità finanziaria e rischio sistemico*, Aracne editrice, 2016.
[33] See A. L. Barabasi, *Link. La nuova scienza delle reti*, Einaudi, Torino 2004.

connected and often in ways that are difficult for human rationality to understand, especially when inadequate methods of analysis are used. Moreover, for many years now, the total volume in value of financial transactions in international financial markets has greatly exceeded the volume in value of transactions in the real economy, thus generating a significantly wide, complex, and interconnected network of financial systems that exposes international financial systems to systemic risks, as has been highlighted previously analysing the various crises that have occurred over the last fifteen years. In the light of what we will be highlighting in this paragraph, we believe that only by analysing economic and financial systems as networks is it possible to discern complex relationships between phenomena of different origins and nature that can generate the propagation of systemic crises.

The study of financial systems as networks thus allows us to discern the way and direction through which a shock could propagate in the system. We can consider financial systems as networks of interconnected economic agents (nodes), whose relations between them are regulated through financial contracts (financial instruments) (links). But the relationships between economic agents are not only formal and explicit (i.e., regulated by financial contracts between two or more operators), they can also be informal and implicit, through - for example - the common investment of two economic agents in the same asset. In this case, it speaks of indirect contagion through portfolio overlapping.

The relationships between the economic agents (nodes) of a network in the economic-financial sector can therefore be of different kinds and tend to change over time. This variety and complexity (and often lack of transparency) of the financial relationships between the various nodes of a network increases the complexity of the financial systems, which produces information asymmetries, risks of moral hazard and, therefore, consequences in the propagation of risks of a systemic nature. As we have already argued above, therefore, the financial crisis born in the USA in 2007-2008, the subsequent - and in some ways consequent - sovereign debt crisis in Europe in 2010-2011 and today the crisis arising from the pandemic and the Chinese debt crisis are clear examples of how it is necessary to approach the study of economic and financial systems through the principles of network science, to aspire to decipher the hidden relationships that bind together complex phenomena.

The origin of network science dates back to 1736 when the Swiss mathematician Euler (1707-1783) inaugurated (perhaps unconsciously) a prolific branch of mathematics known as «graph theory», which is today the basis of modern network science[34]. Over the years, several other mathematicians contributed to the development of this science, but among them who deserve special mention are the

[34] For a comprehensive discussion of network science, refer to A.L. Barabasi, *Link. La nuova scienza delle reti*, Einaudi, Torino 2004; G. Caldarelli, M. Catanzaro, *Scienza delle reti*, Egea, 2016; G. Parisi, *In un volo di storni. Le meraviglie dei sistemi complessi,* Rizzoli, 2021, among others.

Hungarian mathematicians Paul Erdos (1913-1996) and Alfred Renyi (1921-1970), founders of the theory of random networks.

Unlike the random networks of Paul Erdos and Alfred Renyi, which are purely static (i.e., the number of nodes and links tends to remain unchanged over time), the «real» networks (i.e., those with which we are confronted every day in economic systems) are dynamic, because they evolve or tend to grow. In other words, the real nets are characterized by several nodes and connections among them that grow and evolve in time. In particular, in the real world, each network originates from a small nucleus and expands with the addition of new nodes and links that tend to be created according to a mechanism of «preferential connection», i.e., the new nodes, when they have to decide where to connect, tend to prefer the nodes that have more links[31]. Real networks are also characterized by a hierarchy of hubs, where a larger and therefore highly connected node is followed by many other less connected nodes, followed in turn by even smaller nodes. These characteristics of real-world networks are empirically confirmed in interbank markets by In't Veld et al.[35] (2020), who show that financial networks in inter-banking have a configuration similar to a core-periphery structure, where the core forms a network of fully connected nodes, while the peripheral banks are connected only to the core.

In the real world, moreover, networks tend to be self-organizing, i.e., they are an example of how the independent actions of millions of nodes give rise to emergent behaviours, and all these characteristics of real networks must be taken into account when analysing economic phenomena.

In the economic-financial field, the basis of the use of network science to understand the phenomenon of systemic risk is represented by the awareness that individuals, companies, institutions and sovereign states are not independent (as assumed instead by classical economic theory) but rather influence each other. Their operation, far from being completely rational (another fallacious assumption of classical economic theory), is significantly dependent on mutual influence. More simply, as we have already underlined, we live today in a complex and interconnected world. In particular, the work of Acemoglu et al. [36] (2015) highlights that it is the highly interconnected nature of the financial system that contributes to its fragility, as it facilitates the spread of financial distress and solvency problems from one institution to others in an epidemic way. Acemoglu et al. (2015)[34] find that until the volume of negative shocks is below a certain critical threshold, a more diversified pattern of interbank liabilities leads to less fragility, however when shocks exceed that certain critical threshold the high interconnectedness between

[35] See D. In't Veld, M. Van der Leij, C. Hommes, *The formation of a core-periphery structure in heterogeneous financial networks*, in *Journal of Economic Dynamics and Control*, 119, 103972, 2020.
[36] See D. Acemoglu, A. Ozdaglar, A. *Tahbaz-Salehi, Systemic risk and stability in financial networks*, in *American Economic Review*, 105(2), 2015, pp. 564-608.

nodes in the network becomes a source of systemic instability. When negative shocks are larger than a certain threshold, therefore, financial networks in which banks are only weakly interconnected are less prone to the propagation of systemic crises.

Studying economic phenomena through network science thus presupposes considering economic systems as complex networks in which the «nodes» are the economic agents (individuals, firms, sovereign states, etc.) and the «links» are the economic and financial ties that connect them. Moreover, following the mechanisms of «growth» and «preferential connection», characteristic of «real networks», the more a network expands, the more the «hubs» (larger nodes) must expand, swallowing up the smaller ones. In the economic field, therefore, globalization pushes the nodes to expand and therefore mergers and acquisitions are the natural consequence of an expanding economy. The «Achilles heel» of a «small world» and therefore of the real networks are represented by the vulnerability due to the interconnection. An isolated shock can create chain effects that destabilize an entire economic system, and the probability that an isolated shock would undermine an entire system is higher if the nodes affected are the most interconnected. An interesting study in this regard is that of Battiston et al. (2012)[37], which, through the DebtRank index, calculates for each node (bank) of an interbank network how much of the economic value of the network would be lost if that node (bank) failed, confirming that the greatest systemic effects are generated in the case of a crisis of the intermediaries most connected to the other nodes of the system.

Wanting to list the main direct and explicit drivers (channels) of interconnection in economic and financial systems, it is possible to consider the following:

- loans (and in general financial relations) between banks, companies, institutions and countries that feed the channel of direct exposure (illiquidity contagion);
- direct and indirect shareholdings (shareholdings) of companies, businesses and institutions in other companies;
- the sharing of directors between different companies, or the presence of the same directors on the Boards of Directors of different companies (interlocking);
- interconnections between economic sectors and geographical areas which translate into correlations between the share prices of different companies;
- the network of international trade that generates imports and exports between countries and therefore very close links between the trade and payments balances of different sovereign states;
- the information channel, which is atavistically polluted by information asymmetries and the lack of rationality of market participants, who are imperfectly

[37] See S. Battiston, M. Puliga, R. Kaushik, P. Tasca, G. Caldarelli, *Debtrank: Too central to fail? financial networks, the fed and systemic risk*, in *Scientific reports*, 2(1), 2012, pp. 1-6.

informed and tend to make their choices in an often irrational way, especially in particular conditions of systemic uncertainty.

As has already been highlighted in detail in the previous paragraph, through the various channels of direct exposure, the network effects (contagion) produced by the financial relationships between the various nodes of a financial network (banks, companies, states, etc.) can generally be explained. In particular, through the channel of direct exposure, the driver of «illiquidity contagion» explains how a bank tends to withdraw its loans granted to a counterparty as soon as it hears of the risk of the latter's insolvency, inducing this counterparty, in turn, to withdraw its loans from its respective counterparts to recover liquidity. In this way, the crisis spreads throughout the system (financial network) through the links between the various nodes of the network, generating liquidity crises and chain insolvencies and also a general reduction in prices fed by the consequent recessionary and deflationary cycle. Furthermore, if the price of an asset collapses, this event affects not only those who have invested directly in that asset (banks or companies) but also those who have acquired bonds or shares of companies that have invested in that asset.

A second direct channel is represented by the deterioration of interbank assets and the subsequent write-down in the balance sheet of the non-performing assets carried out by the banks with reference - for example - to the loans granted to companies in difficulty (i.e., the assets held by companies in difficulty). This devaluation mechanism impacts banks' balance sheets, reducing the value of assets and forcing greater provisions to reserve, and - as a consequence - generates pro-cyclical recessionary effects due to the contraction of credit and a general reduction in prices in the economic system.

As mentioned, moreover, relations between economic agents are not only formal and explicit and therefore give rise to the so-called direct (and explicit) drivers of interconnection. The relationships (links) between economic agents in a system can also be informal and implicit and thus give rise to indirect links, through - for example - the common investment of two economic agents in the same asset, thus giving rise to an indirect contagion by portfolio overlapping. In this regard, Jiang and Fan [38] find that shocks propagate more rapidly when there is more overlap among the portfolios of banks in a system, i.e., when there are more common investments (assets) in the portfolios of multiple banks, while the propagation of a crisis slows down in the case of more heterogeneous and less overlapping portfolios. In this sense, in the coming years, a source of risk to be carefully monitored will have to be represented by the transition to a low-carbon economy, which may have implications for financial stability and determine a radical change in the allocation of resources. A devaluation of high carbon emission assets could have a significant

[38] See Jiang, S., & Fan, H. (2019). *Systemic risk in the interbank market with overlapping portfolios*. *Complexity*, 2019.

impact on the balance sheets of the institutions that hold these assets in the coming years, thus generating indirect contagion phenomena through portfolio overlapping.

As already highlighted above, the relationships between the economic agents (nodes) of a network can be of various kinds and tend to change over time. This variety and complexity (and often lack of transparency) of the financial relationships between the various nodes of a network tends to increase the complexity of the financial systems and this produces information asymmetries, risks of moral hazard and, therefore, opacity and consequences in the processes of propagation of risks of a systemic nature. This complexity in the relationships between economic agents in a financial system has also been fed since the early years of the new millennium by the evolution (often uncontrolled) of financial engineering, which has made economic-financial systems more interconnected and therefore more complex, linking operators to one another in multiple ways and often unconsciously. Moreover, as already argued, the science of networks teaches us that the mechanisms of «growth» and «preferential connection» lead the «hubs» (larger nodes) to expand in phases of network expansion and thus incorporate smaller nodes. This phenomenon, otherwise known as globalization, however, leads to the risk of extinction of smaller economic operators, such as local banks, whose disappearance or even simple competitive downsizing would, over time, lead to the loss of the extraordinary intangible and relational assets in dowry to these intermediaries, reflexively impoverishing the financial system and also exposing it to greater risks of a systemic nature.

Moreover, we cannot overlook the fact that globalization, by making our world even smaller and thus exposed to the risk of contagion, has also highlighted the limits of the purely micro-prudential approach to the supervision of the financial system. The analysis of financial systems through the science of networks highlights the need for a supervisory approach of a more macro-prudential nature, that considers the multiple and varied interconnections between the various economic agents and, therefore, the potential systemic effects produced by the crisis of a significantly interconnected operator as well as the mitigating role of systemic risk played by certain other smaller intermediaries, such as, for example, cooperative credit banks[39]. As has already been authoritatively pointed out in the literature[40], analysing a complex system such as the financial system through a simplified approach (micro-prudential supervision), i.e., that considers separately the parts of a whole, neglecting instead the interconnections between these parts, inevitably leads to inappropriate regulatory prescriptions, superficial and tendentially pro-cyclical. Hence, the need for an evolution of supervisory approaches in a holistic

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[39] See V. Pacelli, F. Pampurini, A.G. Quaranta, *Co-operative Banks and Financial Stability*, in *International Journal of Business and Social Science*, 11(11), 2020.

[40] See R. Masera, *Per una vera proporzionalità nella regolamentazione bancaria dell'Unione Europea. Le sfide del Coronavirus e di Basilea IV*, Ecra, Roma 2021.

and macro-prudential key, that is, in the direction of a more incisive enhancement of the quality of relationships, interactions and interconnections between operators in the financial system and the direction of an effective proportionality of regulation in the banking field. In this sense, it is believed that the science of networks can provide an indispensable theoretical-conceptual paradigm, useful for allowing the supervisory authorities in the financial field to perceive phenomena, connections and interactions which are probably underestimated and limit many of those competitive distortions which in the course of the last few years have favoured the larger banks[41]. If for no other reason than to create the conditions for a fair competitive comparison which takes into correct consideration the peculiarities of each category of intermediary, also concerning its different systemic imprint and therefore to its different aptitude to determine an acceleration or a brake in the processes of propagation of a systemic crisis and therefore to the different role played in the preservation of financial stability.

4. The sudden and unexpected blackout of international economic activity due to the pandemic has produced the long months of maximum spread of the virus, albeit in different ways and with different intensity, significant effects in every sector of the economy and threatens to determine in the coming months the emergence of new sources of risk of a systemic nature for financial stability. The world today is globalized due to the high level of interconnection of production and distribution, as well as of finance with the real economy, which are two interconnected macrocosms capable of significantly influencing each other. An abrupt contraction in economic activity, such as that caused by the various restrictions due to the Covid-19 pandemic, initially generates liquidity tensions for companies and their lending banks and, later, the liquidity problem risks turning into a solvency problem for companies and, consequently, for banks, which could see their capital ratios deteriorate due to the flow of new non-performing loans, with systemic effects on credit, savings and private investment. Already in the first months of significant contraction in production, trade and economic activity in general following the pandemic, many national governments promptly intervened, supporting the sectors most affected with relief and compensation, but this led to an exponential growth in public debt. Banks have also been given various incentives, essentially through public guarantees, to finance companies in difficulty or to grant moratoria following the contraction of production and trade, but this threatens to lead in the coming months, when public protection will necessarily have to be reduced, to a worsening of the quality of the banks' credit portfolio, with a possible

[41] For a Comprehensive examination of the compliance diseconomies caused by non-proportional bank regulation and, more generally, the competitive distortions generated by financial regulation in favour of larger banks, see R. Masera, *Per una vera proporzionalità nella regolamentazione bancaria dell'Unione Europea. Le sfide del Coronavirus e di Basilea IV*, Ecra, Roma 2021.

increase in non-performing loans and a consequent worsening of capital ratios. The possible insolvencies of lower quality entrusted companies will increase the NPLs of banks, deteriorating the quality of the credit portfolio and the capital ratios, with consequent potential recessionary effects only partially mitigated by public guarantees, which are - in any case - destined to further increase the interconnections between banks and States with an exacerbation of exposure to risks of a systemic nature. In other words, we are living in a complex historical phase in which it will be necessary to find a difficult balance between the need to mitigate the harmful effects of the pandemic and the need to avoid the risk of «drugging» the markets with an excess of liquidity. And this unstable balance will have to be identified at both public and private levels, possibly avoiding confusing the various economic players with schizophrenic economic and monetary policies. In the path towards this desirable equilibrium, the role of the banking system will be fundamental, as banks will have to prove themselves capable of financing those companies that will prove themselves capable of creating sustainable value over time in a profoundly changed market and therefore evaluating with an entrepreneurial spirit, that is, critically and not supine, any clumsy and dirigiste public attempts to orient credit policies.

Otherwise, the risk would be that of artificially diverting or slowing down the free use of entrepreneurial energies, generating an inefficient allocation of capital in the short term with harmful consequences in the medium-long term.

In the hoped-for evolutionary process of the entrepreneurial system, the role of the banking system must not, therefore, be debased by too many regulatory constraints and excessive dirigisme of economic policies, which otherwise risk generating pro-cyclical effects of a recessive nature and also a risk, due to their intrinsic rigidity, to gag the autonomy of banks and slow down the necessary process of selection of the most resilient companies in the credit market. This evolutionary process will have to bear the cost, including the social cost, of the disappearance of some companies and some productive segments (those that will prove to be anachronistic in the new post-pandemic world) and it will therefore be necessary to guarantee flexibility in the labour market and investments in personnel training to accompany the process of productive and entrepreneurial evolution. And to do all this will require courage, «good debt» (quoting President Mario Draghi) and therefore investments that increase productivity and competitiveness. But also, greater cohesion and political and social solidarity (at all levels) to reduce inequalities and generate a global social renaissance.

In the medium term, therefore, the solution cannot be to persevere in short-sighted and unconditional welfarism, which risks generating laziness and immobility in the business world and creates the conditions for opportunistic or moral hazard behaviour. Instead, credit policy must be based on a careful analysis of creditworthiness and the entrepreneurial formula that pushes companies to innovate and compete and that, as a consequence, favours the generation of a more modern and competitive entrepreneurial fabric. If we wanted to give a sense, or rather a positive meaning to this tragic pandemic, we should interpret it as an opportunity for the business world to evolve. An opportunity, however, that we can't allow to miss, or else the survival of our economic system as we have understood it up to now.

As mentioned above, the multiple government measures to support the liquidity of businesses and the public guarantees granted to banks in favour of loans to the private sector, on the one hand, temporarily sterilize the harmful effects of the blockage of economic activity following the pandemic, on the other hand, create the basis for a future exacerbation of the level of systemic risk, because they indissolubly bind the banks with the sovereign States that are guarantors of the credit provided by them.

In a systemic crisis, the potential chain of contagion does not stop at banks and businesses but also involves the states, which collect lower tax revenues due to the contraction of the economy, increase their public debt to support current spending and will see their reputation in the markets diminished as soon as the exceptional systems of public aid to the economy necessarily downsizing, with negative effects on the rates paid on the debt issued[42]. And this is especially true for those states characterized by high public debt, such as Italy, and therefore endowed with little autonomous spending capacity. Moreover, the close link between the state and the banks, the main holders of the issued sovereign debt, ends up - as highlighted above - tying public fates with private ones and these further fuel the risk of contagion with systemic effects.

The Covid-19 pandemic is an idiosyncratic, exogenous, unexpected shock, which has affected all countries more or less symmetrically, but which threatens to produce - in the absence of adequate transnational policies - asymmetrical effects on the various economies, varying the degree of structural fragility of the different economic systems. Exactly as happened from a medical point of view with the different effects of the virus on human beings, also from an economic point of view the pandemic will produce asymmetric effects on the different countries. In countries with a past structural fragility, the pandemic threatens to produce devastating effects, while in the more solid countries the effects will be more rapidly absorbed and, indeed, these countries will improve their relative competitiveness on the international landscape as a result of the worsening conditions of competing countries on the market and the consequent strategic, productive and commercial opportunities. In addition, the more solid countries, i.e., those with lower public debt and greater productive capacity, will be able to invest greater resources to further increase the productivity of their productive system concerning the more indebted

[42] See H. Altınbaş, V. Pacelli, E. Sica, *The determinants of sovereign bond yields in the EMU: New empirical evidence*, in *International Journal of Economics and Finance*, 10(5), 2018.

countries, and this would further increase the competitive spread between the companies of the stronger and weaker nations. The pandemic therefore could represent an extraordinary opportunity for strategic and commercial dumping for stronger countries to the detriment of weaker ones.

The pandemic will also produce greater effects in countries where the GDP of the most affected sectors (tourism, transport, entertainment and trade) is most significant. And the effects will be asymmetrical also in the labour market (between more protected and less protected workers and systems), with repercussions on the social climate and internal demand.

Just as in the real economy, the effects of the pandemic will also be asymmetrical in the financial markets. As a result of the pandemic, financial markets are more volatile but also more liquid, due to the extraordinary amount of financial resources that international monetary and fiscal policy authorities are providing to financial systems to compensate for the contraction in economic activity. Greater liquidity and greater volatility create extraordinary profit opportunities in the markets, which are however often seized exclusively by larger institutional investors, who can predict and govern volatility, having adequate knowledge, information and means.

In the light, therefore, of what has been argued above, it is easy to foresee that the economic crisis due to the pandemic will increase inequality in income and wealth and, therefore, social inequalities, thus exacerbating the effects of a systemic nature. Let us not forget that the crisis that broken out in 2007 originated in the USA also because of evident inequalities and disparities of an economic, social and regulatory nature.

A further aspect that should not be underestimated from a systemic perspective is certainly represented by the impact of the ecological transition on financial systems. In this dimension, the phenomenon of systemic risk intrinsic to the pandemic and that of environmental and climate risk have in common the evidence that no one can say they are safe. This is an immediate indication of their common nature as «totalitarian» systemic risks of the same enormous natural ecosystem: the world ecosystem. In other words, we could recall the risk of a general breakdown of the ship: if the ship is on fire, no one is saved from fire or death at sea. The only factual rule is the same as always: if you want to save yourself, you must save the ship or help save the ship, obeying rules of necessary solidarity.

Scientific research has long highlighted the need to reduce global warming and promote green investments and this awareness is now widely spread at the social and political levels. The scientific community has begun to measure the impacts that the ecological transition can produce on real and financial markets and international political authorities have launched multiple initiatives aimed at making the ecological transition a reality. In such a scenario, the interconnection between finance and the environment appears central, since the need to rethink a model of sustainable development with a transition to a green economy cannot disregard the key role played by financial intermediaries, who are called to promote sustainable investments compatible with the desired green transition.

Also, in the light of what has been argued above, to understand the complex holistic nature of the phenomenon of systemic risk, today we cannot disregard the integrated and prospective analysis, through the logical-conceptual schemes borrowed from the science of networks, of the multiple and often obscure relationships that bind the various economic, political, social, health and environmental phenomena.

Starting from this conviction and wishing to offer a guideline for reflection, in extraordinary historical periods such as the one we are living and are preparing to live in the coming years, the central and enlightened role of States in a strategic and operational transnational horizon appears indispensable. Disrupting financial relations and creating small, independent and disconnected autarchic nuclei is not a viable solution in today's world. In other words, systemic risk today cannot be eliminated or fragmented; it must be lived with and managed in a forward-looking, proactive and integrated manner. A small and interconnected world, and therefore significantly exposed to contagion risks, requires risk sharing, social solidarity, «intelligent» forecasting and control tools as well as forms of public guarantees, especially transnational ones, which - possibly without interfering with the free deployment of entrepreneurial energies - protect and safeguard the market in the event of a crisis of individual operators. In this sense, great expectations should be placed on the completion and, hopefully, enlargement of the economic and banking union in Europe, both from a financial and, above all, a political perspective. It is clear to all that in the coming years we will live in a more indebted, interconnected and «small» world, in which forms of community public guarantees, risk-sharing, and social solidarity will prove increasingly indispensable to preserve competitiveness and sustainability of our economic and social system.

Vincenzo Pacelli, Ida Claudia Panetta and Maria Melania Povia

SYSTEMIC RISK AND NETWORK SCIENCE: A BIBLIOMETRIC LITERATURE REVIEW TO SET FUTURE RESEARCH AGENDA *†

ABSTRACT

La stima del rischio sistemico nelle reti di istituzioni finanziarie costituisce ancora una sfida per i *policy makers*. La complessità via via crescente dei network finanziari determina una sempre maggiore difficoltà nella possibilità di attenuare il rischio sistemico e amplifica il modo in cui attraverso la specifica topologia delle connessioni si può propagare il fallimento di una singola entità nel network. Lo scopo principale del nostro studio è quello di comprendere meglio l'importanza per la ricerca del rischio sistemico e dell'interconnessione tra le istituzioni finanziarie utilizzando tecniche bibliometriche per l'analisi della letteratura esistente. In particolare, si intende contribuire ad analizzare l'evoluzione delle pubblicazioni sul rischio sistemico e sulle reti, integrando le precedenti review della letteratura di tipo narrativo con analisi method-based. I risultati suggeriscono che il rischio sistemico e le reti finanziarie hanno registrato una rapida crescita nell'ultimo decennio e ciò può contribuire a una futura nuova agenda di ricerca sull'argomento.

Estimating systemic risk in networks of financial institutions is still a challenge in policymaking. The complexity of financial networks may increase the difficulty of mitigating systemic risk and how the topology of connections can propagate the failure of an individual entity through the network in the system. Our study's primary purpose is to apply the bibliometric method to understand further the importance of systemic risk and interconnectedness among financial institutions. Moreover, this contributes to analysing the evolution of systemic risk and networks publications, considering influential aspects of the literature such as authors, themes, and articles. Results suggest that systemic risk and financial networks have experienced rapid growth during the last decade, and this can contribute to a future new research agenda on the topic.

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KEYWORDS

Rischio sistemico – scienza delle reti – crisi finanziarie

Systemic risk – network science – financial crisis

SUMMARY: 1. Introduction – 2. Background and research question development – 3. Research design – 4. Results – 5. Conclusions

1. Understanding and controlling systemic risk has become a crucial social and economic topic in the literature. The 2007 crisis of financial markets, possibly the worst economic disaster since the Great Depression of the 1930s, the 2010 sovereign debt crisis, the COVID-19 crisis, and the recent war in Ukraine have brought to the fore how markets linkages and financial integration are impacted by crises, extraordinary events with a wide potential scope. During the past two decades, the succession of these crises has been given increased attention to the study of the financial system's architecture in creating systemic risk and the relationship between the structure of the financial network and the extent of financial contagion.

The study of financial systems as networks thus makes it possible to discern the way and direction through which a shock might propagate through the system. Indeed, we can consider financial systems as networks of interconnected economic agents (nodes), whose relationships are regulated through financial contracts (links) and which grow and evolve.

In financial economics, the basis for using network science to understand systemic risk is the realisation that individuals, firms, institutions and sovereign states are not independent but influence each other. Globalisation pushes the nodes to become more significant; therefore, mergers and acquisitions are the natural consequence of an expanding economy.

In the light of the above, it is believed that only by analysing economic and financial systems as networks is it possible to discern complex relationships between phenomena of different origins and nature that can generate the propagation of systemic crises[1].

Systemic risk has long been identified as a potential contagion mechanism or impact that starts from the failure of a financial institution and propagates through the financial system and to the real economy itself[2]. A constant concern of bank regulators is that the collapse of a single bank could bring down the financial system as a whole. Economic systems are increasingly built on interdependencies and the dynamic interaction of many different agents, creating complex networks.

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[1] V. Pacelli, *Rischio sistemico e scienza delle reti*, Bancaria 12, Roma 2021.

[2] S. Poledna, S. Marínez-Jaramillo, F. Caccioli, S. Thurner, *Quantification of systemic risk from overlapping portfolios in the financial system*, Journal of Financial Stability 52, 2021.

Dense interconnections could represent a dangerous mechanism for propagating shocks, leading to a more fragile financial system.

For this reason, estimating systemic risk in network science represents an important challenge for regulators to anticipate systemic events and reduce systemic risk, ensuring the objective of financial stability.

Synthesising the literature, we define systemic risk as "*the risk of a systemic default, i.e. the default of a large portion of the financial system that starts from the failure of a financial institution and propagates through the financial system*".

The failure of a financial institution, or a group of institutions, depends on the network of financial exposures among institutions, and their complexity and interconnectedness can increase vulnerabilities. Indeed, systemic risk can be quantified from the network structure, the dynamical evolution analysis, and the nodes' interaction.

Moreover, Battiston et al. (2012)[3] introduce a novel measure of systemic impact, DebtRank, defined as the "*number measuring the fraction of the total economic value in the network that is potentially affected by the distress or the default of node*". Mezei and Sarlin (2018)[4] present a new approach to measuring systemic risk in networks and suggest using RiskRank.

Network science can contribute to a quantitative assessment of systemic risk and estimate systemic events in a network, improving the financial system's stability.

The worldwide economic crisis of 2007-09 has turned attention to the need to analyse systemic risk in complex financial networks. Different contributions have developed the study of the relationship between the financial networks and systemic risk, suggesting how the structure of the financial networks can mitigate or amplify systemic risk along various channels. Therefore, in this paper, we use the bibliometric method to understand the evolution of research on systemic risk and interconnectedness among financial institutions and highlight the literature’s progress in recent years.

Our work is structured in the following way. Section 2 summarises the previous literature review on systemic risk and network science, giving the proper ground to root our research questions. Section 3 describes the research design, describing the metrics used to conduct our literature review, and data sample building up process. Section 4 is devoted to present most influential aspects of literature investigated and the results of the bibliometric analysis. Finally, Section 5 offers the future research question and proposes some considerations for the study's conclusion.

2. The recent troubled years for the global economy have led to increased interest in the role of the financial network in systemic risk literature.

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[3] S. Battiston, M. Puliga, R. Kaushik, P. Tasca, G. Caldarelli, *DebtRank: Too Central to Fail? Financial Networks, the FED and Systemic Risk*, Scientific Reports 2, 541, 2012.

[4] J. Mezei, P. Sarlin, *RiskRank: Measuring interconnected risk*, EconPapers 68, Örebro 2018, p. 41 ss.

Many studies on systemic financial risk have shown that interconnectedness can facilitate risk sharing, which can help minimise the uncertainty faced by individual agents: diversification reduces risk and improves stability. However, more numerous and complex interlinkages among financial markets can serve as a channel for propagating shocks and amplifying existing information asymmetries or other externalities and market frictions[5].

Financial institutions create multilayer networks characterised by holding exposures to joint assets, a network of trading relationships and exposures between financial institutions[6]. Thus, topological features of financial networks influence how easily distress can propagate within the system. Market integration and diversification are processes that can stabilise the financial system. Still, these factors can contribute to instability and amplify financial distress, making significant crises more likely to happen[7].

Roukny et al. (2018)[8] and Benoit et al. (2015)[9] analyse the importance of financial networks in understanding systemic events. The structure of those networks can facilitate the capacity of regulators to estimate systemic risk in terms of expected losses, and it can decrease the difficulty of mitigating systemic risk and the social cost of financial crises.

Recent research on financial networks offers essential insights into systemic risk measurement methods by studying contagious links and fragile network structures. However, methods that focus only on the investments and relationships of a few large institutions can ignore several potential crises[10]. Thus, this analysis can incentivise banks to choose investments and partners that maximise the financial system's overall value and understand that systemic risk depends on complex interdependencies[11].

According to Silva et al. (2017)[12], many articles analysed the systemic importance of specific institutions in the literature, but an essential gap in comparative research on systemic risk measurement is evident.

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[5] D. Acemoglu, A. Ozdaglar, A. Tahbaz-Salehi, *Systemic risk and stability in financial networks*, American Economic Review 105, 2015, p. 564 ss.

[6] S. Battiston, M. D'Errico, S. Gurciullo, *DebtRank and the network of leverage*, The Journal of Private Equity 20, 2016, p. 58 ss.

[7] M. Bardoscia, S. Battiston, F. Caccioli, G. Caldarelli, *Pathways towards instability in financial networks*, Springer Nature 8, 14416, 2017.

[8] T. Roukny, S. Battiston, J.E. Stiglitz, *Interconnectedness as a source of uncertainty in systemic risk*, Journal of Financial Stability 35, 2021, p. 93 ss.

[9] S. Benoit, J.E. Colliard, C. Hurlin, C. Pérignon, *Where the Risks Lie: A Survey on Systemic Risk*, Social Science Research Network 2577961, Rochester 2015.

[10] A.R. Neveu, *A survey of network-based analysis and systemic risk measurement*, Journal of Economic Interaction and Coordination 13, 2018, p. 241 ss.

[11] M.O. Jackson, A. Pernoud, *Systemic Risk in Financial Networks: A Survey*, Annual Review of Economics 13, 2021, p. 171 ss.

[12] W. Silva, H. Kimura, V.A. Sobreiro, *An analysis of the literature on systemic financial risk: A survey*, Journal of Financial Stability 28, 2017, p. 91 ss.

As summarised in Table 1, all previous literature reviews use a *narrative* approach. These reviews encompass a variety of topics, including relatively new fields of research based on the importance of financial networks in understanding systemic events; despite this variety of subjects and approaches, a clear focus on the relationship between network science research and systemic risk is still not yet evident. Therefore, we would like to follow a bibliometric analysis to complement with quantitative analysis of previous narrative reviews focused on the interplay of financial networks and systemic risk, trying to picture the evolution of systemic risk and networks research, also considering influential aspects of the literature such as authors, themes, and articles. Following this aim, we try to answer one central research question: "*How is the literature on systemic risk issues and financial networks evolving in recent years?*".

Table 1. Summary of literature review on systemic risk and financial networks[13].

Title	Authors	Topic	Methodology
Pathways towards instability in financial networks.	Bardoscia et al. (2017)	• Analyse how market integration and diversification can amplify financial distress.	Narrative
Interconnectedness as a source of uncertainty in systemic risk.	Roukny et al. (2016)	• Focus on the importance of financial networks in understanding systemic events.	Narrative
Where the Risks lie: a survey on Systemic risk*.	Benoit et al. (2016)	• Focus on the extensive literature on systemic risk.	Narrative
The price of complexity in financial networks.	Battiston et al. (2016)	• Analyse the complexity of financial networks.	Narrative
Systemic risk in Financial Networks: a survey*.	Jackson and Pernoud (2021)	• Analyse an overview of the relationship between financial networks and systemic risk.	Narrative
Modeling systemic risk to the financial system: a review of additional literature.	Markeloff et al. (2012)	• Focus on rigorous assessment of the performance of various systemic risk models.	Narrative
A survey of Network-based analysis and systemic risk measurement*.	Neveu (2018)	• Focus on systemic risk and the network approach.	Narrative
Application of systemic risk measurement methods: a systematic review and meta-analysis using a network approach*.	Dičpinigaitienė and Novickytė (2018)	• Analyse systemic risk measurement methods.	Narrative
An analysis of the literature on systemic financial risk: A survey.	Silva et al. (2017)	• Focus on systemic financial risk.	Narrative

3. After having defined in previous parts the aim of the paper, in this section, we describe all the steps followed in our analysis, namely:

a. The definition of techniques to conduct the literature review.

b. The sample selection, identifying articles related to systemic risk and financial networks to be processed.

[13] The asterisk at the end of a paper stands for all the studies included in review.

c. The run of the quantitative analysis and reporting of main findings.

To answer the research question regarding analysing the evolution of systemic risk and financial networks literature, we adopted bibliometric measures (step 1) as an essential vehicle for highlighting and motivating emerging scholarship[14]. Bibliometric reviews analyse and classify bibliographic material by framing representative summaries of the extant literature[15] from a more objective, quantitative perspective[16]. Bibliometric approaches are increasingly used in the literature reviews across different disciplines due to several factors, including the introduction of software tools, cross-disciplinary, and the capacity to synthesise a large volume of data[17]. Indeed, this methodology has been applied in different fields of business research, including business strategy[18], human resources[19], marketing[20] [21] [22] , management[23] [24], electronic commerce[25] and finance[26] [27].

There are two main technique categories for bibliometric analysis: performance analysis and science mapping[28]. Performance analysis recognises the importance of

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[14] A. Khan, J.W. Goodell, M.K. Hassan, A. Paltrinieri, *A bibliometric review of finance bibliometric papers*, Finance Research Letters 102520, 2021.

[15] N. Donthu, S. Kumar, D. Pattnaik, *Forty-five years of Journal of Business Research: A bibliometric analysis*, Journal of Business Research 109, 2020, p. 1 ss.

[16] G. Albort-Morant, D. Ribeiro-Soriano, *A bibliometric analysis of international impact of business incubators*, Journal of Business Research 69, 2016, p. 1775 ss.

[17] N. Donthu, S. Kumar, D. Mukherjee, N. Pandey, W.M. Lim, *How to conduct a bibliometric analysis: An overview and guidelines*, Journal of Business Research 133, 2021, p. 285 ss.

[18] S. Kumar, R. Sureka, W.M. Lim, S. Kumar Mangla, N. Goyal, *What do we know about business strategy and environmental research? Insights from Business Strategy and the Environment*, Business Strategy and the Environment (BSE) 30, 2021b, p. 3454 ss.

[19] N. Andersen, *Mapping the expatriate literature: a bibliometric review of the field from 1998 to 2017 and identification of current research* fronts, The International Journal of Human Resource Management 32, 2021, p. 4687 ss.

[20] K. Backhaus, K. Lügger, M. Koch, *The structure and evolution of business-to-business marketing: A Citation and co-citation analysis*, Industrial Marketing Management 40, Budapest 2011, p. 940 ss.

[21] C. Hu, M. Song, F. Guo, *Intellectual structure of market orientation: a citation/co-citation analysis*, Marketing Intelligence & Planning 37, 2019, p. 598 ss.

[22] S. Sammie, B.R. Chabowsky, *Knowledge structure in international marketing: a multi-method bibliometric analysis*, Journal of the Academy of Marketing Science 40, 2012, p. 364 ss.

[23] O. Ellegaard, J.A. Wallin, *The bibliometric analysis of scholarly production: How great is the impact?*, Scientometrics 105, 2015, p. 1809 ss.

[24] I. Zupic, T. Čater, *Bibliometric Methods in Management and Organization*, Organizational Research Methods journal 18, 2015, p. 429 ss.

[25] S. Kumar, W.M. Lim, N. Pandey, J. Christopher Westland, *20 years of Electronic Commerce Research*, Electronic Commerce Research 21, 2021a, p. 1 ss.

[26] B. Durisin, F. Puzone, *Maturation of Corporate Governance Research, 1993-2007: An Assessment*, Corporate Governance an International Review 17, 2009, p. 266 ss.

[27] M.K. Linnenluecke, X. Chen, X. Ling, T. Smith, Y. Zhu, *Research in finance: A review of influential publications and a research agenda*, Pacific-Basin Finance Journal 43, 2017, p. 188 ss.

[28] N. Donthu, S. Kumar, D. Mukherjee, N. Pandey, W.M. Lim, *How to conduct a bibliometric analysis: An overview and guidelines*, cit., p. 285 ss.

contributions of research constituents to a given field[29] [30] [31]. Two of the most important measures are the number of publications and citations per year or research constituent.

Moreover, science mapping represents the relationships between research constituents[32] [33] [34]. The analysis is based on the intellectual interactions and structural connections among research constituents[35]. Science mapping includes relevant techniques: citation analysis, co-citation analysis, bibliographic coupling, co-word analysis and co-authorship.

According to the main objective of this paper, we decide to analyse the evolution of systemic risk and financial networks literature using the following techniques: i) citation analysis, ii) co-citation analysis, iii) co-word analysis, iv) co-authorship analysis, and v) content analysis.

In particular, the citation analysis allows to identify the influential aspects of systemic risk literature and network science, and it breaks down into two areas of analysis: local citation and global citation. Local citation analysis measures the number of citations a document has received from papers included in the analysed collection. Instead, global citation, analysis means the total citations and measures the number of citations a document has received from documents indexed on a bibliographic database.

Co-citation analysis is essential to explain research clusters by examining the co-citation pairs and network, which can provide significant and objective insights into the intellectual structure of the selected research discipline[36].

The co-word analysis is also called the semantic network and refers to the relationships among the keywords considered as the unit of analysis. Thus, the assessment of the keywords of scientific documents allows for establishing the research trends in a specific field.

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[29] M.J. Cobo, A.G. López-Herrera, E. Herrera-Viedma, F. Herrera, *An approach for detecting, quantifying, and visualizing the evolution of a research field: A Practical application to the Fuzzy Sets Theory field*, Journal of Informetrics 5, 2011, p. 146 ss.

[30] N. Donthu, S. Kumar, D. Mukherjee, N. Pandey, W.M. Lim, *How to conduct a bibliometric analysis: An overview and guidelines*, cit., p. 285 ss.

[31] A.R. Ramos-Rodrígue, J. Ruíz-Navarro, *Changes in the intellectual structure of strategic management research: A bibliometric study of the Strategic Management Journal*, Strategic Management Journal 25, 2004, p. 981 ss.

[32] H.K. Baker, S. Kumar, N. Pandey, *Forty years of the Journal of Futures Markets: A bibliometric overview*, Journal of Futures Markets 41, 2021, p. 1027 ss.

[33] M.J. Cobo, A.G. López-Herrera, E. Herrera-Viedma, F. Herrera, *An approach for detecting, quantifying, and visualizing the evolution of a research field: A Practical application to the Fuzzy Sets Theory field*, cit., p. 146 ss.

[34] A.R. Ramos-Rodrígue, J. Ruíz-Navarro, *Changes in the intellectual structure of strategic management research: A bibliometric study of the Strategic Management Journal*, cit., p. 981 ss.

[35] N. Donthu, S. Kumar, D. Mukherjee, N. Pandey, W.M. Lim, *How to conduct a bibliometric analysis: An overview and guidelines*, cit., p. 285 ss.

[36] G. Calabretta, B. Durisin, M. Ogliengo, *Uncovering the Intellectual Structure of Research in Business Ethics: A journey Through the History, the Classics, and the Pillars of "Journal of Business Ethics"*, Journal of Business Ethics 104, 2011, p. 499 ss.

Co-authorship analysis is based on a tool used to identify the key organisations and scientists and their associations.

Finally, the content analysis is a systematic analysis that aims to discover relationships, themes, and concepts about the data to produce a complete examination[37].

Bibliometric analysis is conducted with two software, Biblioshiny and VOSviewer. The Biblioshiny software is a shiny app providing a web interface for the Bibliometrix package of R[38]. VOSviewer is a powerful visualisation software tool for creating maps based on network data and visualising and exploring these maps[39][40]. VOS viewer is particularly helpful in running bibliometric mapping and visualising bibliometric networks and identity clusters.

The second step regards the building up process of a significant sample of papers in the field to be analysed through bibliometric techniques and map the scientific production on systemic risk and network science. We selected the Scopus database as the source of the bibliographic data since it is the largest database of peer-reviewed literature in social science research[41], covering scientific journals, books and conference proceedings[42], widely used in literature reviews. In performing our selection process, we followed the so-called PRISMA method (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) displayed in fig. 1. The PRISMA statement allows for a better understanding of the selection process and improves reporting quality and transparency[43].

After several simulation tests, we determined the most appropriate selection of keywords to include the most significant number of papers on systemic risk in application to networks science (tab. 2). The keywords combination selected is: "systemic risk" and "network*" and its derivatives with "and" Boolean operator. This result comes from a keyword combination analysis. After an initial screening, we found the combination "systemic risk", "contagion" and "financial network": the word "financial" was eliminated because 'systemic risk' encompasses the whole group. Afterwards, we detected the keyword combination "systemic risk" and "network*",

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[37] K. Krippendorff, *Content analysis: An Introduction to its methodology*, Thousand Oaks, CA: Sage, 2013.

[38] M. Aria, C. Cuccurullo, *bibliometrix: An R-tool for comprehensive science mapping analysis*, Journal of Informetrics 11, 2017, p. 959 ss.

[39] H.K. Baker, S. Kumar, D. Pattnaik, *Twenty-five years of Review of Financial Economics: A bibliometric overview*, Review of Financial Economics 38, 2020, p. 3 ss.

[40] A. Khan, M.K. Hassan, A. Paltrinieri, A. Dreassi, S. Bahoo, *A bibliometric review of takaful literature*, International Review of Economics & Finance 69, 2020, p. 389 ss.

[41] H.K. Baker, S. Kumar, D. Pattnaik, *Twenty-five years of Review of Financial Economics: A bibliometric overview*, cit., p. 3 ss.

[42] V.K. Singh, P. Singh, M. Karmakar, J. Leta, P. Mayr, *The journal coverage of Web of Science, Scopus and Dimensions: A comparative analysis*, Scientometrics 126, 2021, p. 5113 ss.

[43] K. Knobloch, U. Yoon, P.M. Vogt, *Preferred reporting items for systematic reviews and meta-analyses (PRISMA) statement and publication bias*, Int J Surg. 39, 2011, p. 91 ss.

which allows the inclusion of the different suffixes through the asterisk at the end of the searched word. The exact keyword search is presented below: TITLE-ABS-KEY (systemic AND risk AND network*).

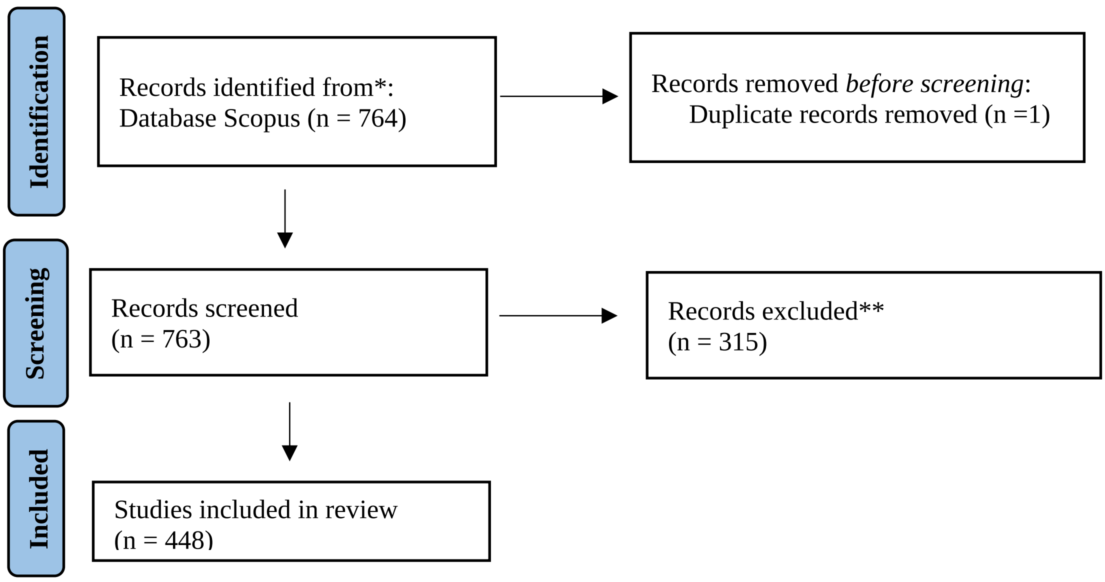
Table 2. Sample of articles on systemic risk

Keywords	*Scopus*
Systemic risk	2709
Financial networks	4668
Contagion	2796
Systemic risk measurement	102
Systemic risk; contagion; network	174
Systemic risk and contagion	361
Systemic risk and network*	**448**
Systemic risk and stability	476

Then the sample was assessed using the following inclusion criteria: time range, subject area, selection of scientific articles and English language. In particular, the selection criteria contributed to the first screening of the sample, limiting the thematic areas of reference in: "economics" and "finance", business and management (ECO-BUSI), period from 2008 to 2021, excluding Conference Paper, Book chapter, Books, Editorial, Retracted, Conference Review and Letters.

Thus, we reorganised the dataset extracted (n=764), removing duplicate records (n=1) and eliminating those not compliant with the filter chosen (n=315).

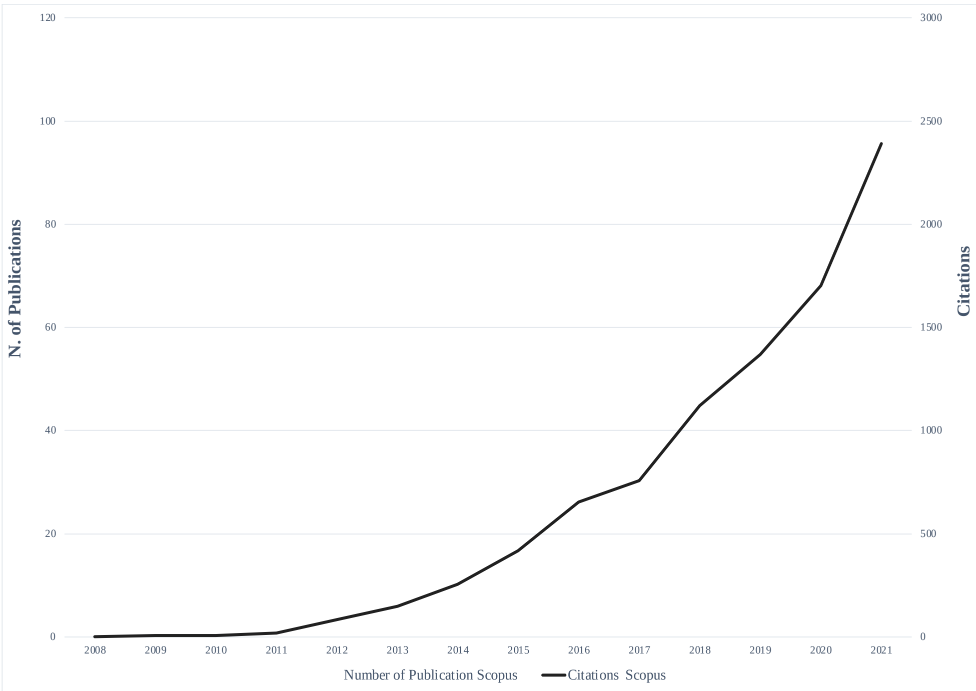
Figure 1. PRISMA 2020 flow diagram for the included studies



The last stage (3) regards the quantitative analysis of the main sample results multiples tests; the main results, presented in the following section, allowed us to outline the evolution of research streams on systemic risk and network science.

4. As summarised in Fig. 1, our final sample consists of 448 scientific articles, which results big enough to run a bibliometric analysis[44]. Looking at the sample distribution by year (Fig. 2), we observed that few articles in the sample were published in or before 2008, confirming that the topics surged greater attention only after the financial crises of 2007-8.

Figure 2. Sample distribution by year (number of papers and number of citations)



After the financial crises, we recorded steady scholarly growth in the literature and its citation impact, with a clear upward trend after 2011 suggesting increased academic interest in systemic risk and network science. From 2009 onwards, articles on systemic financial risk are regularly published yearly, but with low frequency until 2011. From 2012 onwards, with the worsening of the financial crisis and the pandemic crisis in 2020, the number of articles on systemic financial risk increased significantly.

Additional observations are provided, considering citations. Table 3 confirms an exponential increase in the number of citations after 2011 following the increasing interest paid to the topic. The citation analysis identifies the influential aspects of

[44] N. Danthu, S. Kumar, D. Mukherjee, N. Pandey, W.M. Lim, *How to conduct a bibliometric analysis: An overview and guidelines*, Journal of Business Research, 13, 2021, pp.285ss.

systemic risk literature and network science. We were able to extract 8935 citations from 448 articles with Bibliometrix, applying graphical parameters: number of documents (20) and measure (Total Citations). Table 4 shows the top 25 most-cited articles, divided by year, local citations and global citations. The most local cited article is Acemoglu (2015), followed by Billio (2012), Battiston (2012), and Glasserman (2015). Instead, the total citation analysis shows that the most cited article is Billio (2012), followed by Acemoglu (2015). These articles are systemic risk, banking, and interbank markets focused, while the other three most-cited articles are risk governance and financial network focused. Only one article received more than ten citations, Fricke (2015) in local citation analysis (Fig. 3). The citation analysis helps understand the formation and scope of research streams.

We conduct bibliometric co-citation analysis with VOSviewer software, which identifies the research streams or clusters in the literature in the form of networks[45].

Co-citation analysis, as mentioned, is essential to explain research clusters by examining the co-citation pairs and network, which can provide significant and objective insights into the intellectual structure of the selected research discipline[46].

We created a map based on bibliographic data, applying the counting method (full counting), unit of analysis (cited authors) and a minimum number of citations of an author (20). As a result, of the 15497 authors, only 344 meet the threshold. For each of the 344 authors, the total strength of the co-citation links with other authors has been calculated.

Table 3. Summary of literature review on systemic risk and financial networks[47].

Year	Number of Publications	%	Citations
2008	-	-	-
2009	5	1,12%	7
2010	5	1,12%	8
2011	6	1,34%	20
2012	12	2,68%	85
2013	20	4,46%	148
2014	21	4,69%	256
2015	35	7,81%	417
2016	42	9,38%	654
2017	32	7,14%	756
2018	54	12,05%	1120
2019	62	13,84%	1370
2020	59	13,17%	1702
2021	95	21,21%	2392
Total	448		8935
h-index			47

[45] J. Kim, S. Mcmillan, *Evaluation of Internet Advertising Research: A bibliometric Analysis of Citations from Key Sources*, Journal of Advertising 37, 2008, p. 99 ss.
[46] G. Calabretta, B. Durisin, M. Ogliengo, *Uncovering the Intellectual Structure of Research in Business Ethics: A journey Through the History, the Classics, and the Pillars of "Journal of Business Ethics"*, Journal of Business Ethics 104, 2011, p. 499 ss.
[47] The asterisk at the end of a paper stands for all the studies included in review.

Figure 4 defines five clusters for the co-citation analysis: 344 items, 50615 links and 735127 total link strength. In particular, Battiston with 341 links and 431 citations, Thurner with 335 links and 223 citations, Kapadia with 342 links and 257 citations, Gallegati with 336 links and 189 citations, and Adrian with 342 links and 174 citations.

Co-word analysis refers to the relationships among the keywords considered as the analysis unit. Thus, the assessment of the keywords of scientific documents allows for establishing the research trends in a specific field.

Table 4. Most Global Cited Documents (Bibliometrix)

Paper	DOI	Total Citations	TC per Year	Normalized TC
BILLIO M, 2012, J FINANC ECON	10.1016/j.jfineco.2011.12.010	897	81,5455	5,6356
ACEMOGLU D, 2015, AM ECON REV	10.1257/aer.20130456	581	72,625	9,57843
BATTISTON S, 2012, J ECON DYN CONTROL	10.1016/j.jedc.2012.04.001	315	28,6364	1,97906
VAN ASSELT MBA, 2011, J RISK RES	10.1080/13669877.2011.553730	284	23,6667	3,47755
GLASSERMAN P, 2015, J BANK FINANC	10.1016/j.jbankfin.2014.02.006	244	30,5	4,02261
GEORG C-P, 2013, J BANK FINANC	10.1016/j.jbankfin.2013.02.032	193	19,3	4,24176
CACCIOLI F, 2014, J BANK FINANC	10.1016/j.jbankfin.2014.05.021	172	19,1111	5,3991
HAUTSCH N, 2015, REV FINANC	10.1093/rof/rfu010	171	21,375	2,81912
ALLEN F, 2012, J FINANC ECON	10.1016/j.jfineco.2011.07.003	145	13,1818	0,91099
MARKOSE S, 2012, J ECON BEHAV ORGAN	10.1016/j.jebo.2012.05.016	142	12,9091	0,89215
BATTISTON S, 2012, J FINANC STAB	10.1016/j.jfs.2012.01.002	141	12,8182	0,88586
PALMA JG, 2009, CAMB J ECON	10.1093/cje/bep037	141	10,0714	4,63816
ROGERS LCG, 2013, MANAGE SCI	10.1287/mnsc.1120.1569	140	14	3,07692
GLASSERMAN P, 2016, J ECON LIT	10.1257/jel.20151228	139	19,8571	5,74041
FRICKE D, 2015, COMPUT ECON	10.1007/s10614-014-9427-x	137	17,125	2,2586
KOU G, 2019, TECHNOL ECON DEVELOP ECON	10.3846/tede.2019.8740	130	32,5	14,77798
POLEDNA S, 2015, J FINANC STAB	10.1016/j.jfs.2015.08.001	130	16,25	2,14319
DIEBOLD FX, 2015, J FINANC ECONOM	10.1093/jjfinec/nbv021	128	16	2,11022
CHIESA V, 2011, J PROD INNOVATION MANAGE	10.1111/j.1540-5885.2011.00818.x	120	10	1,46939
AMINI H, 2016, MATH FINANC	10.1111/mafi.12051	119	17	4,91445
MARTINEZ-JARAMILLO S, 2014, J ECON DYN CONTROL	10.1016/j.jedc.2014.01.009	114	12,6667	3,57848
BARGIGLI L, 2015, QUANT FINANC	10.1080/14697688.2014.968356	112	14	1,84644
ANAND K, 2015, QUANT FINANC	10.1080/14697688.2014.968195	98	12,25	1,61564
IN 'T VELD D, 2014, J BANK FINANC	10.1016/j.jbankfin.2014.08.006	98	10,8889	3,07623
HÄRDLE WK, 2016, J ECONOM	10.1016/j.jeconom.2016.02.013	96	13,7143	3,9646

Figure 3. Most Local Cited Documents (Bibliometrix)

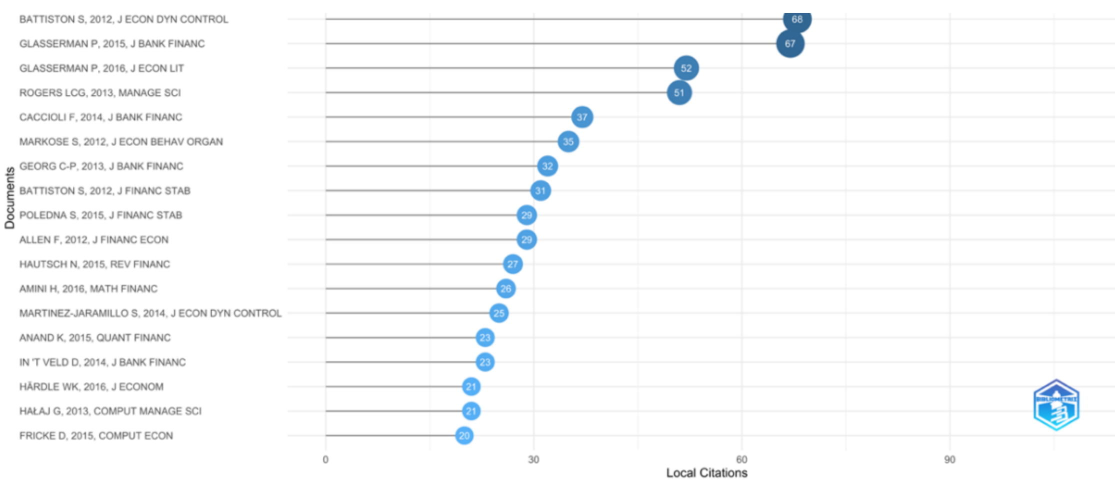
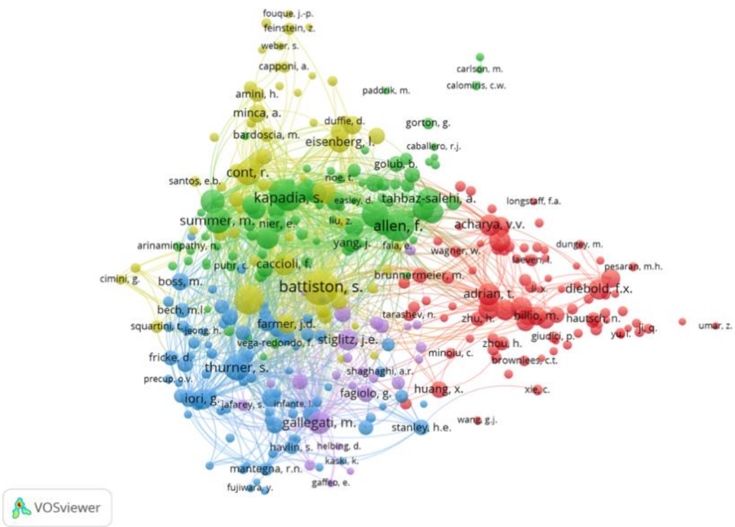


Figure 4. Co-citation Analysis (VOSviewer)



VOSviewer software was used to generate a keyword co-occurrence clustering view in systemic risk and network science. A total of 59 have been selected from 1576 keywords, and a co-occurrence analysis was performed on these 59 keywords, as shown in Figure 5. For each of the 59 keywords, the total strength of the co-occurrence links with other keywords is calculated. The keywords with the greatest total link strength are selected. In Figure 5, the node area and font size depending on the keyword's weight value. The more significant the weight value, the more times the keyword appears; the line between nodes indicates that a keyword appears in common with another. The thickness of the connection line indicates the co-occurrence strength between the two keywords[48].

We identified an important limitation of these analyses associated with the evidence that the VOSviewer method does not reduce an ample space of related terms that are easier to understand but are also indicative of the actual partitions of interrelated concepts in the literature under consideration. Indeed, we find an essential association between terms, but there is no selection of semantic relationships.

From the analysis, eight clusters can be obtained. The topics are summarised for each cluster, and the keywords in each cluster are listed.

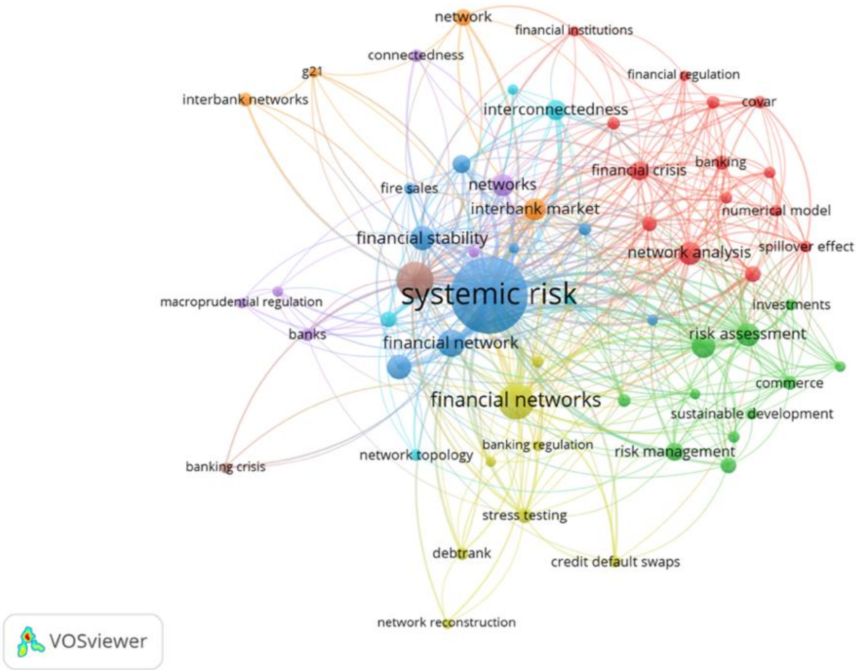
Systemic risk, financial networks, network analysis, risk assessment, networks and interconnectedness are among the most highly co-occurring keywords with occurrence weights of 479, 147, 64, 88, 42, 40, respectively. The 1576 keywords were able to form 8 clusters: cluster 1 (blue), cluster 2 (green), cluster 3 (red), cluster 4 (yellow), cluster 5 (purple), cluster 6 (orange), cluster 7 (brown) and cluster 8 (light blue).

[48] J.K. Tamala, E.I. Maramag, K.A. Simeon, J.J. Ignacio, *A bibliometric analysis of sustainable oil and gas production research using VOSviewer*, Cleaner Engineering and Technology 7, 2022.

In Figure 6, the frequency of keywords is less before 2017. The early studies between 2016 and 2017 focus on the banking crisis, interbank market and financial stability. In 2018 researchers introduced the systemic risk theme, risk assessment and interconnectedness. More recent studies after 2019 focus on the relationship between systemic risk network science. Indeed, the concept of systemic risk the networks science is relatively new and appeared consistently between 2018 and 2019. The literature on systemic risk and networks science is developing, and, specifically, it is concentrated on the importance of the financial networks that can alert to the prominent role institutions play in the system.

This emerging topic explains how a series of failures can propagate through the network in a cascading process[49].

Figure 5. Co-word Analysis (VOSviewer)



[49] S. Sinha, M. Thess, S. Markose, *How unstable are complex financial systems? Analyzing an inter-bank network of credit relations*, New Economic Windows 13, 2013, p. 59 ss.

Figure 6. Co-word Analysis (VOSviewer)

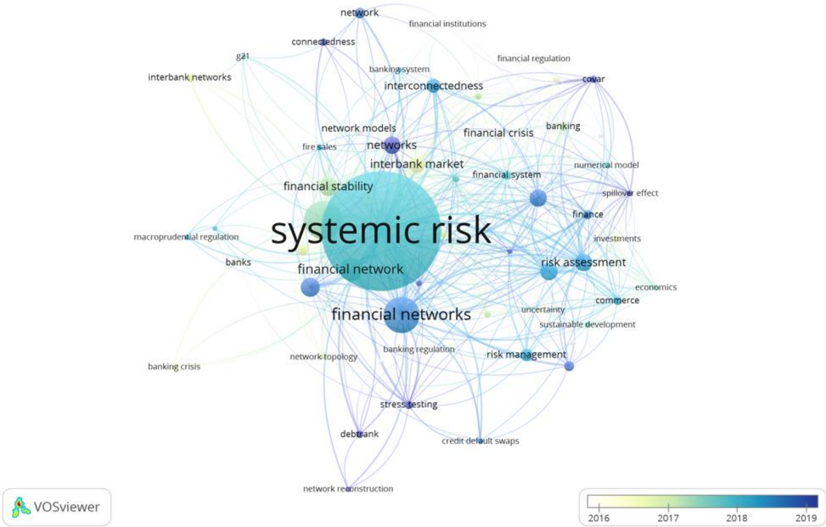


Fig. 6 Co-word Analysis.
Source: VOSviewer.

To define the co-authorship network of authors in the sample, we identify the network visualisation map with VOSviewer characterised by links of items based on the number of co-authored documents. This analysis is based on a tool used to determine the key organisations and scientists and their associations.

Fig. 7 shows the network visualisation map for these items and defines that the several authors were grouped in three clusters. In these clusters, the authors with more co-authored documents are Battiston with 12 studies, and Thurner with 8 works. Further, the top 20 influential/authors in systemic risk and network science are recognised. Our findings show that the top three authors/researchers are Battiston with 12 articles and Silva and Steinbacher with eight products each (Table 5).

Figure 7. Co-Authorship Analysis (VOSviewer)

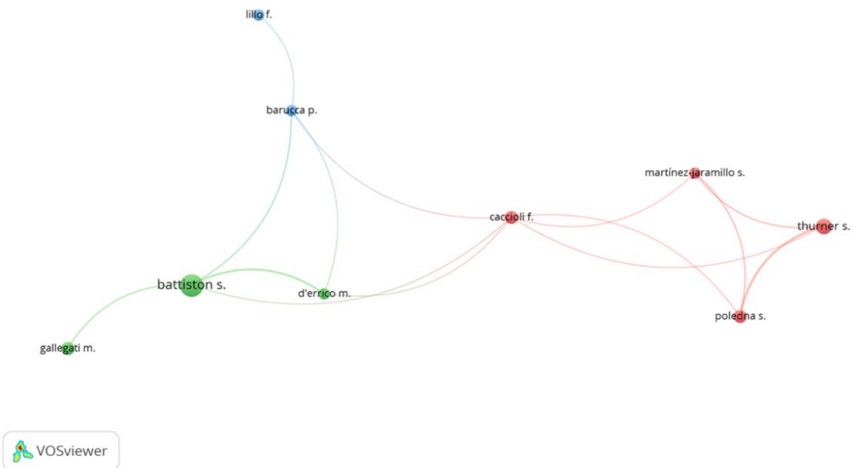


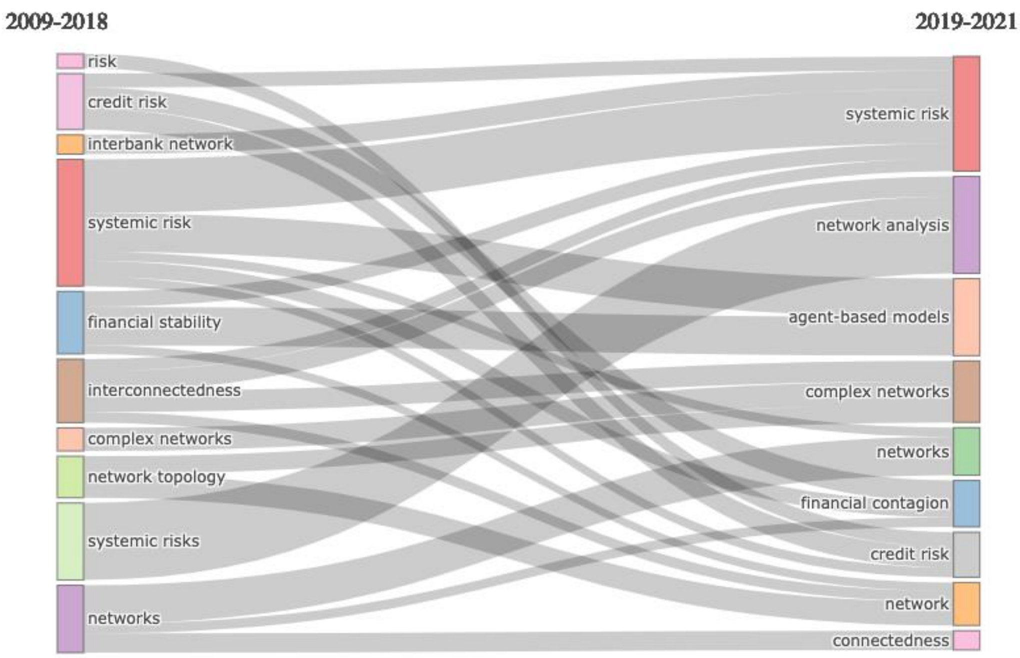
Table 5. Most Relevant Authors (Bibliometrix)

Authors	Articles	Articles Fractionalized
BATTISTON S	12	3,41
SILVA TC	8	2,42
STEINBACHER M	8	3,00
THURNER S	8	2,78
TABAK BM	7	2,08
CACCIOLI F	6	1,56
GALLEGATI M	6	1,9
GIUDICI P	6	2,5
POLEDNA S	6	1,95
BARUCCA P	5	1,25
D'ERRICO M	5	1,26
LI H	5	1,32
LILLO F	5	1,53
MARTÍNEZ-JARAMILLO S	5	1,20
SARLIN P	5	2,67
SPELTA A	5	2,17
VERAART LAM	5	3,00
ZHANG W	5	1,33
AMINI H	4	1,33
BARDOSCIA M	4	0,98

Content analysis is a systematic analysis that aims to discover relationships, themes, and concepts about the data to produce a complete examination[50]. Bibliometrix software was used to generate the Thematic Evolution in the field of systemic risk and network science, selecting the author's keywords. As shown in Figure 8, the themes' evolution is evident from 2009-to 2018 and from 2019 to 2021. After the 2007 crisis of financial markets and the 2010 sovereign debt crisis, the most influential themes were concentrated on the theoretical conception of the risks, interconnectedness, and networks. Finally, after 2019 there was a thematic evolution focused on models, network analysis and the financial contagion phenomenon. Indeed, literature examines systemic risk from a theoretical perspective for the first period, then combines the theory's evolution with the network analysis by applying scientific models.

[50] K. Krippendorff, *Content analysis: An Introduction to its methodology*, Thousand Oaks, CA: Sage, 2013.

Figure 8. Thematic Evolution (Bibliometrix)

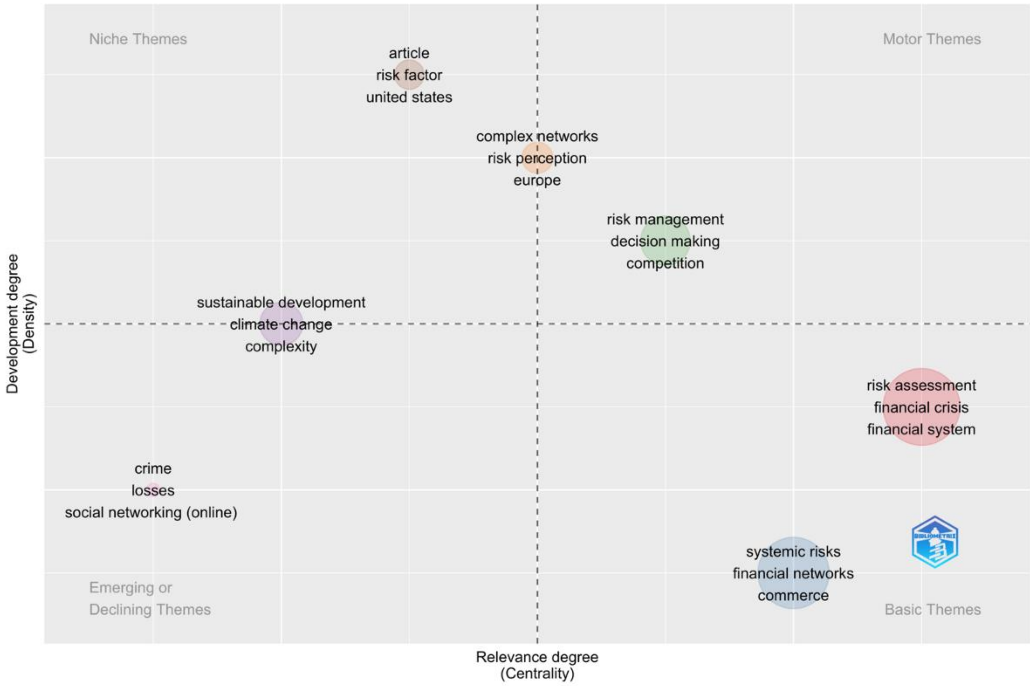


Using co-word analysis to draw clusters of keywords, we can also consider the themes, whose density and centrality help classify themes and map them in a two-dimensional diagram.

A thematic map (Fig. 9) is a very intuitive analysis that allows identifying themes according to the quadrant in which they are placed: upper-right quadrant: motor themes; lower-right quadrant: basic themes; lower-left quadrant: emerging or disappearing themes; upper left quadrant: very specialised/niche themes[51].

[51] M.J. Cobo, A.G. Lopez-Herrera, E. Herrera-Viedma, F. Herrera, *An approach for detecting, quantifying, and visualizing the evolution of a research field: A practical application to the fuzzy sets theory field*, Journal of Informetrics 5, 2011, p. 146 ss.

Figure 9. Thematic Map (Bibliometrix)



The thematic map exploits the Keywords Plus field, associated with Thomson Reuters editorial experts and is supported by a semi-automated algorithm. Keywords Plus terms can capture an article's content with depth and variety[52]. The upper-right quadrant shows the motor themes, which are more developed in the literature and are characterised by both high centrality and density. Among the "motor themes" the main concerns are risk management, decision making, and competition related to risk governance. The upper-left quadrant shows high-density themes but with a low centrality. In this quadrant, it is possible to find the themes of sustainable development, climate change and risk factors that are recurring words associated with the Co-word analysis cluster. In the lower-left quadrant are the emerging or declining themes. In this research, the themes of crime, losses and social networking are emerging. Finally, the lower-right quadrant shows the themes that are basic and transversal. These themes concern general topics transversal to the different research areas of the field. In this area, we find systemic risks, financial networks, commerce, risk assessment, financial crisis and financial system.

5. The bibliometric literature review in this chapter aims to give a basic worldwide overview of research publications on systemic risk and networks science, integrating with quantitative analysis of previous narrative reviews on the topic. The literature on

[52] V. Della Corte, G. Del Gaudio, F. Sepe, F. Sciarelli, *Sustainable Tourism in the Open Innovation Realm: A Bibliometric Analysis*, Journal of Sustainability 11, 2019.

systemic risk has grown continuously over the years. It will continue to grow to better understand and manage risk in the financial system by modelling it in terms of financial networks.

The study of systemic risk associated with network science represents a new research challenge for the years to come.

In particular, we recorded an increasing interest in climate-related financial risks and the critical role of financial network models applied for the climate stress test and the transition to a low carbon economy that can have implications for financial stability. Furthermore, research in the field is progressively focused on new ways to assess (and possibly prevent) systemic risk using network science and manage it.

Moreover, this paper analyses the evolution of systemic risk and network publications, also considering influential aspects of the literature.

Results suggest that systemic risk and financial networks have experienced rapid growth during the last decade, which can contribute to a future new research agenda on the topic by providing different approaches to the study and a more accurate view of the phenomenon.

Caterina Di Tommaso and Vincenzo Pacelli

CDS MARKET AS A TRANSMISSION CHANNEL OF SYSTEMIC RISK. EMPIRICAL EVIDENCE FROM COVID-19 AND UNCONVENTIONAL MONETARY POLICY*†

ABSTRACT

Il contagio da covid-19 ha generato improvvise e significative contrazioni dell'economia reale a livello globale e questo ha inevitabilmente prodotto effetti sui mercati finanziari. Questo lavoro di ricerca mira a indagare l'effetto della politica monetaria non convenzionale sui mercati dei CDS sovrani e bancari applicando la metodologia dell'event study. Il mercato dei CDS, sia sovrano che bancario, funge da meccanismo di propagazione degli impulsi di politica monetaria e da potenziale canale di trasmissione di una crisi sistemica. Le banche hanno sofferto la politica monetaria non convenzionale a causa degli effetti negativi di tali politiche espansive sul margine di intermediazione e, quindi, sulla redditività.

The covid-19 infection has generated sudden and significant contractions in the real economy on a global level and this has inevitably produced effects on the financial markets. This paper aims at investigating the effect of unconventional monetary policy on sovereign and bank CDS markets by applying an event study methodology. The sovereign and banks' CDS market act as a propagation mechanism for monetary policy impulses as well as potential channels for transmitting a systemic crisis. Banks have suffered the unconventional monetary policy due to the negative effects of these expansionary policies on the intermediation margin and, thus, on profitability.

KEYWORD

Crisi pandemica- Politica monetaria- Mercato dei CDS

Pandemic crisis-Monetary policy-CDS market

SUMMARY: 1. Introduction- 2. Methodology and data- 3. (Segue:) Reaction of sovereign CDS market to the monetary policy announcement- 3. (Segue:) Reaction of banks CDS market to the monetary policy announcement- 4. Conclusion

* Paper audited according to the system for *peer review*

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1. The outbreak of the pandemic crisis has questioned the financial stability of the whole system[1] and has brought an increase in the overall systemic risk. An external shock has caused a shortfall in the financial markets and has increased sudden uncertainty about the economic recovery[2]. All around the world, the government authorities have started to prompt the economy by adopting different measures and policies. In this regard, national governments and the European Commission have allocated large amounts of liquidity and aid that have allowed the system to bear the weight of the serious uncertainty caused by the pandemic crisis.

This paper aims at investigating the effect of the unconventional monetary policies adopted in response to the pandemic crisis on the country's and banks' risk. Specifically, we apply an event study methodology to measure the impact that the different monetary policies have had on the CDS market in the short-term period. Given the strong impact that the pandemic crisis and the related monetary policy measures have had on the financial markets, recent studies have examined the reaction of the stock and CDS market to the interventions aimed at economic recovery. Studies focusing on the stock market reaction have pointed out that the movement of these markets has been dramatic and more severe than the 2007-2008 financial crisis[2,3,4]. The reactions of the stock markets of the different countries are linked to the severity of the pandemic[2,3,5] and the country's and sectors' characteristics[6,7,8,9]. Studies about the reaction of the sovereign CDS market show that the COVID-19 pandemic had a

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[1] See Dunbar, K. (2022). *Impact of the COVID-19 event on U.S. banks' financial soundness. Research in International Business and Finance*, 59. https://doi.org/10.1016/j.ribaf.2021.101520

[2] See Zhang, D., Hu, M., & Ji, Q. (2020). *Financial markets under the global pandemic of COVID-19. Finance Research Letters*, 36, 101528. https://doi.org/10.1016/j.frl.2020.101528

[3] See Heyden, K. J., & Heyden, T. (2021). *Market reactions to the arrival and containment of COVID-19: An event study. Finance Research Letters*, 38(May 2020), 101745. https://doi.org/10.1016/j.frl.2020.101745

[4] See Sansa, N. A. (2020). *The Impact of the COVID-19 on the Financial Markets: Evidence from China and USA. Electronic Research Journal of Social Sciences and Humanities*, 2(II).

[5] See Yang, H., & Deng, P. (2021). *The Impact of COVID-19 and Government Intervention on Stock Markets of OECD Countries. Asian Economics Letters*, 1(4). https://doi.org/10.46557/001c.18646

[6] See Chen, H. C., & Yeh, C. W. (2021). *Global financial crisis and COVID-19: Industrial reactions. Finance Research Letters*. https://doi.org/10.1016/j.frl.2021.101940

[7] See Erdem, O. (2020). *Freedom and stock market performance during Covid-19 outbreak. Finance Research Letters*, 36.

[8] See Harjoto, M. A., & Rossi, F. (2020). *Market Reaction to the COVID-19: Evidence from the Emerging and Developed Markets*. Available at SSRN 3794135.

[9] See He, P., Sun, Y., Zhang, Y., & Li, T. (2020). *COVID–19's Impact on Stock Prices Across Different Sectors—An Event Study Based on the Chinese Stock Market. Emerging Markets Finance and Trade*, 56(10), 2198–2212. https://doi.org/10.1080/1540496X.2020.1785865

significant impact on market sovereign default risk[10,11,12]. Finally, Wei and Han[13] focusing on a government bond, stock, exchange rate and credit default swap markets find that the emergence of the pandemic has weakened the transmission of monetary policy to financial markets to a more significant degree. They underline that neither conventional nor unconventional monetary policies have significant effects on all four of the financial markets.

Our paper contributes to this emerging literature on the impact of the pandemic crisis in several ways. First, to the best of our knowledge, this is the first paper examining the CDS market reactions to monetary policy measures on a cross-country level. Using a sample of European countries and banks, we employ an event study to measure the short-term CDS market reactions. Second, our paper offers a deeper analysis because it investigates the macroeconomic and the microeconomic perspective of the extraordinary monetary policy interventions. Studying the macroeconomic perspective is very important because the shortfall of the markets from the COVID-19 pandemic could trigger a cascade of sovereign defaults and great financial instability by causing a systemic crisis. From a macroeconomic perspective, the paper offers a focus on the reaction of the country's risk to monetary policy interventions. Investigating the microeconomic perspective is of paramount importance because the interbank network can undermine financial stability by amplifying financial distress. From a microeconomic perspective, the analysis focuses on the reaction of the bank's CDS spreads to the unconventional monetary policy.

Our paper provides several findings: (i) the unconventional monetary policy has increased the uncertainty on the sovereign and banks' CDS market; (ii) the quantitative easing policy has the power to calm the sovereign CDS market but not the bank's CDS markets; (iii) the monetary policy interventions increase the inequalities between the strongest (Core) and weakest (GIIPS) countries and their production systems; (iv) the banks have suffered the unconventional monetary policy due to the negative effects of these expansionary policies on the intermediation margin[14] and, thus, on the profitability of EU banks[15].

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[10] See Andrieș, A. M., Ongena, S., & Sprincean, N. (2021). *The COVID-19 Pandemic and Sovereign Bond Risk. North American Journal of Economics and Finance*, 58(August), 101527. https://doi.org/10.1016/j.najef.2021.101527

[11] See Cevik, S., & Öztürkkal, B. (2020). *Contagion of Fear : Is the Impact of COVID-19 on Sovereign Risk Really Indiscriminate ? IMF Working Paper*, 263.

[12] See Daehler, T., Aizenman, J., & Jinjarak, Y. (2020). *Emerging Markets Sovereign Spreads and Country-Specific Fundamentals During COVID-19. NBER Working Paper*, 27903.

[13] See Wei, X., & Han, L. (2021). *The impact of COVID-19 pandemic on the transmission of monetary policy to financial markets. International Review of Financial Analysis*, 74(37), 101705. https://doi.org/10.1016/j.irfa.2021.101705

[14] See Rizwan, M. S., Ahmad, G., & Ashraf, D. (2020). *Systemic risk: The impact of COVID-19. Finance Research Letters*, 36(May). https://doi.org/10.1016/j.frl.2020.101682

[15] See Aldasoro, I., Fender, I., Hardy, B., & Tarashev, N. (2020). *Effects of Covid-19 on the Banking Sector: the Market's Assessment. BIS Bulletin*, 12, 1–7.

The rest of the paper is organized as follows. In the next section, we describe the sample and methodology. Section 3 provides and discusses the empirical results. Finally, Section 4 concludes.

2. We employ a standard event study methodology[16] to determine whether the announcement of a monetary policies measure – the "event"— has a significant and immediate impact on the countries and banks' CDS markets. We estimate a market model for each country and bank based on daily CDS returns in a variety of event widows where day 0 is the day of the monetary policy announcement. We assess returns over different windows to evaluate whether the CDS market can anticipate or lag the reaction. In keeping with previous studies[3,10], we calculate the abnormal returns as:

$$AR_{it} = R_{it} - (\alpha_i + \beta_i R_{mt}) \qquad (1)$$

where AR_{it} is the abnormal CDS return in which "abnormal" is the difference between the observed returns and the expected returns for each country or bank over the different event windows, R_{it} is the observed CDS return and $(\alpha_i + \beta_i R_{mt})$ is the expected CDS return estimated for each event. To estimate R_{mt}, we use Datastream Europe 5 Year CDS index as a proxy for the sovereign CDS market[10] and Datastream Europe Banks 5 Year CDS index as a proxy for banks CDS market. For each event window we carry out OLS estimates of daily abnormal returns and aggregate them to estimate the cumulative abnormal returns (CAR) in each event window. The event study is performed over an estimate window of 250 trading days, i.e. [-260; -11] where $t=0$ is the event day.

To measure the response of the CDS market to the unconventional monetary policy, we consider 3 different event windows[3, 10]: [-1;1], [-1; 5] and [-1;10].

To investigate the reaction of the country and banks' CDS market to the announcement of the monetary policy measures, we construct different samples. A first sample contains the CDS spreads of EU countries. Specifically, we consider Ireland, Italy, Portugal and Spain (so-called GIIPS countries)[17], and France, Germany, and Netherlands (so-called Core countries). A second sample includes all listed banks based in the European countries listed above with a liquid CDS market. The bank sample is composed of 31 listed banks. In both samples, we use the 5-year CDS mid-quotes on senior unsecured debt contracts. The period of our analysis ranges from March 2020 to March 2021. The data about the CDS market are extracted from Datastream. Summary statistics are reported in Table 1. The dates of the monetary policy measures are extracted by the official ECB website[18] and have been divided by announcements concerning the interest rate changes and the quantitative easing policies (Table A1).

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[16] See MacKinlay, A. C. (1997). *Event studies in economics and finance. Journal of economic literature*, 35(1), 13-39.

[17] Unfortunately, we have had to exclude Greece from our analysis because the CDS market for this country is illiquid.

[18] https://www.ecb.europa.eu/press/pr/activities/mopo/html/index.en.html

Table 1: Summary statistics for the sovereign and banks CDS market
The table reports the summary statistics of the sovereign (Panel A) and banks (Panel B) CDS market. The CDS spreads are expressed in basis points (bps). In panel B, the number of banks for each country is indicated in brackets.
Source: Database Datastream.

Country	*Mean*	*Median*	*Dev. Std*	*Min*	*Max*
		PANEL A. Country CDS spreads			
France	9.419	6.700	5.430	5.020	26.140
Germany	6.825	5.550	2.447	4.780	13.780
Ireland	15.274	13.710	6.949	5.110	43.820
Italy	76.015	68.900	32.389	30.080	169.350
Netherlands	10.285	9.350	2.829	7.360	17.570
Portugal	33.147	28.440	16.442	16.310	87.920
Spain	31.303	26.705	15.123	10.440	86.720
		PANEL B. Average bank CDS spreads			
France (5)	38.111	35.260	12.328	19.640	30.060
Germany (6)	77.053	74.930	29.550	33.470	117.87
Ireland (3)	256.294	74.170	267.532	60.340	634.372
Italy (6)	111.661	93.695	61.548	18.780	210.000
Netherlands (4)	107.121	95.945	84.873	14.360	233.71
Portugal (2)	212.891	255.925	82.958	79.430	293.801
Spain (5)	263.466	131.08	277.286	21.550	770.551

3.1 In this section, we present the results of the event study divided by sovereign and bank CDS market. The reaction of the sovereign CDS market to unconventional monetary policy measures are reported in Table 2. In line with previous studies[10,13], the results in Panel A of Table 2 show that the decision of the ECB to maintain the interest rates unchanged amplifies the negative effect as it adds uncertainty among investors. The expansive monetary policy has caused an overall increase in the average price of EU sovereign CDS spreads suggesting the investor's concerns about the effects potentially destabilizing that such marked expansionary policies may have on the solvency of the sovereign debt.

The results in Panel B of Table 2 show the reaction of the CDS market to the announcement about the quantitative easing policies. On the contrary of the previous results, the CDS market decreases after the announcement about the net asset purchases implying that the quantitative easing policy has a reassuring character and helps to calm markets[3,19]. In conclusion, the announcements of changes in policy rate add uncertainty

[19] See Moessner, R., & de Haan, J. (2021). *Effects of monetary policy announcements on term premia in the euro area during the COVID-19 pandemic. Finance Research Letters*, August 2020, 102055. https://doi.org/10.1016/j.frl.2021.102055

to the market by increasing the transmission of monetary policy to the sovereign CDS market whereas the quantitative easing policy has weakened the transmission of monetary policy to the sovereign CDS market to a more significant degree.

Table 2: Event study results for the sovereign CDS market.
The table reports the results of the event study for the sovereign CDS market. The results in Panel A refer to the announcement of the changes in interest rate. The results in Panel B refer to the announcement of the quantitative easing policy.
*, **, *** indicate the significance at the 10%, 5% and 1% level respectively.

Event window	*[-1;+1]*	*[-1;+5]*	*[-1;10]*
	A. Change in interest rate		
CAR (bps)	0.0187	0.0317	0.0162
Bootstrap	(0.000)***	(0.000)***	(0.0454)**
Wilcoxon test	(0.000)***	(0.000)***	(0.0417)**
	B. Quantitative easing policy		
CAR (bps)	-0.2482	-0.2559	-0.2928
Bootstrap	(0.0316)**	(0.0071)***	(0.0000)***
Wilcoxon test	(0.0006)***	(0.0000)***	(0.0002)***

In running the event study divided by GIIPS and Core countries, the hypothesis that we want to test is whether the precarious starting condition relating to debt sustainability in the GIIPS Countries may have influenced the reaction of the CDS market to the unconventional monetary policies adopted by the ECB, compared to the more solid Core Countries. The results are shown in Table 3. The empirical results show differences in the reaction of GIIPS and Core countries to announcements of monetary policy measures. The decision of the ECB to maintain a stable interest rate and to conduct a quantitative easing policy has reduced the country risk of Core countries and increased that of GIIPS countries. The cumulative abnormal returns of PIIGS countries are positive and significant in all event windows implying that, in the short-term, the monetary policy interventions have added uncertainty to the markets and the investors have questioned the debt sustainability of countries with a precarious condition[10]. On the contrary, the unconventional monetary policy measures have increased the investor's confidence about the sustainability of the Core country's public debt[20]. In conclusion, the fragilities shown by the GIIPS Countries on the sovereign debt market have been exacerbated by the uncertainty deriving from the pandemic crisis and investors have expressed greater concern for the debt sustainability of these countries compared to the Core countries which, instead, showed greater solidity. The results of our analysis seem to confirm the view that the pandemic crisis will increase

[20] See Linciano, N., Caivano, V., Fancello, F., & Gentile, M. (2020). *La Crisi Covid-19. Impatti E Rischi Per Il Sistema Finanziario Italiano in Una Prospettiva Comparata (The Covid-19 Crisis. Impacts And Risks For The Italian Financial System In A Comparative Perspective). In CONSOB Occasional Report.* https://doi.org/10.2139/ssrn.3663335

the inequalities between the strongest (Core) and weakest (GIIPS) countries and their production systems[21].

Table 3: Event study results divided by GIIPS and Core countries
The table reports the results of the event study for the sovereign CDS market divided by GIIPS (columns 1, 2 and 3) and Core (columns 4, 5 and 6) countries. The results in Panel A refer to the announcement of the changes in interest rate. The results in Panel B refer to the announcement of the quantitative easing policy.
*, **, *** indicate the significance at the 10%, 5% and 1% level respectively.

	GIIPS countries			*CORE countries*		
	1	*2*	*3*	*4*	*5*	*6*
Event window	*[-1;+1]*	*[-1;+5]*	*[-1;10]*	*[-1;+1]*	*[-1;+5]*	*[-1;10]*
			A. Change in interest rate			
CAR	0.3131	0.3079	0.2849	-1.0122	-1.0237	-1.0368
Bootstrap	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***
Wilcoxon test	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***
			B. Quantitative easing policy			
CAR	0.3294	0.3186	0.2723	-1.0185	-1.0218	-1.0463
Bootstrap	(0.0001)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***
Wilcoxon test	(0.0001)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***	(0.0000)***

3.2 Table 4 shows the reaction of the bank's CDS market to the monetary policy announcements. In line with Aldasoro[15], the results underline that the monetary policy interventions have risen the CDS spreads. Therefore, the monetary policy interventions have exacerbated the negative effect of the pandemic crisis on the banking soundness. The outbreak of the pandemic has underlined the important role of the conventional and unconventional monetary policies on EU banks' credit risk [22]

The increase in the CDS spread may be due to the negative effects of these expansionary policies on the intermediation margin[14] and, thus, on the profitability of EU banks[15]. Our results confirm the view that the unconventional monetary policy affects the bank's CDS market due to the significant interconnections between the balance sheets of banks and those of sovereign entities which expose financial systems to significant contagion risks. Probably, due to this interconnection and the current and prospective effects of this crisis on the economic, capital and financial balances sheet of the banks, the main actors that will suffer the pandemic crisis and its repercussions are the banks.

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[21] See Perugini, C., & Vladisavljević, M. (2021). *Social stability challenged by Covid-19: Pandemics, inequality and policy responses. Journal of Policy Modeling,* 43(1), 146–160. https://doi.org/10.1016/j.jpolmod.2020.10.004

[22] See Katsampoxakis, I. (2021). *ECB's unconventional monetary policy and spillover effects between sovereign and bank credit risk. EuroMed Journal of Business,* April. https://doi.org/10.1108/EMJB-09-2020-0103

Table 4: Event study results for the banks CDS market
The table reports the results of the event study for the bank's CDS market. The results in Panel A refer to the announcement of the changes in interest rate. The results in Panel B refer to the announcement of the quantitative easing policy.
*, **, *** indicate the significance at the 10%, 5% and 1% level respectively.

Event window	*[-1;+1]*	*[-1;+5]*	*[-1;10]*
	A. Change in interest rate		
CAR (bps)	0.0335	0.0374	0.0342
Bootstrap	(0.0700)*	(0.0245)**	(0.001)***
Wilcoxon test	(0.2127)	(0.0121)**	(0.0231)**
	B. Quantitative easing policy		
CAR (bps)	0.0332	0.0368	0.0342
Bootstrap	(0.0791)*	(0.0250)**	(0.0043)***
Wilcoxon test	(0.3277)	(0.0201)**	(0.0052)***

4. Covid-19 has underlined the interconnection between the markets and how the pandemic crisis can spread to the real economy and the financial markets. In general, the pandemic crisis has brought an increase in the overall systemic risk that has pushed the regulatory authorities to introduce measures to reduce the systemic risk.

In this study, we highlight the impact of the monetary policy on the sovereign and banks' risk by analysing the monetary policy interventions taken by the ECB in response to the pandemic crisis. The paper aims at investigating the effect of unconventional monetary policy measures on the sovereign and banks' CDS market.

We find that the decision of the ECB to maintain the interest rate stable and negative has increased the uncertainty in the market whereas the decision to conduct a quantitative easing policy has the power to calm the sovereign CDS market. However, our results differentiate about country's group. The unconventional monetary policy measures have increased the investor's confidence about the sustainability of the Core country's public debt but they have added uncertainty to the sovereign CDS markets of GIIPS countries.

The reaction of the bank's CDS market to the monetary policy interventions is positive and significant suggesting that the increase of the CDS spread may be due to the negative effects of these expansionary policies on the intermediation margin and, thus, on the profitability of EU banks. Our results confirm the view that the unconventional monetary policy affects the bank's CDS market due to the significant interconnections between the balance sheets of banks and those of sovereign states which expose financial systems to significant contagion risks by increasing the overall systemic risk.

Appendix

Table A1. ECB monetary policy announcements.
The table reports the announcement divided by announcements related to the changes of interest rate (Panel A) and those related to the quantitative easing policy (Panel B).
Source: https://www.ecb.europa.eu/press/pr/activities/mopo/html/index.en.html

Date	*ECB announcements*
	Panel A. Interest rate announcements
12 March 2020 04 June 2020 16 July 2020 10 September 2020 29 October 2020 10 December 2020 21 January 2021 11 March 2021	The interest rate on the main refinancing operations and the interest rates on the marginal lending facility and the deposit facility will remain unchanged at 0.00%, 0.25% and -0.50% respectively.
	Panel B. Quantitative easing policy
12 March 2020	(1) Longer-term refinancing operations (LTROs) will be conducted (2) TLTRO III operations will support bank lending to those affected most by the spread of the coronavirus. (3) A temporary envelope of additional net asset purchases of €120 billion will be added until the end of the year. (4) Reinvestments of the principal payments from maturing securities purchased under the APP will continue.
18 March 2020	ECB announces €750 billion Pandemic Emergency Purchase Programme (PEPP)
07 April 2020	ECB announces package of temporary collateral easing measures
30 April 2020	(1) The conditions on the targeted longer-term refinancing operations (TLTRO III) have been further eased. (2) ECB recalibrates targeted lending operations to further support the real economy. (3) ECB announces new pandemic emergency longer-term refinancing operations
04 June 2020	(1) The envelope for the pandemic emergency purchase programme (PEPP) will be increased by €600 billion to a total of €1,350 billion. (2) The horizon for net purchases under the PEPP will be extended to at least the end of June 2021. (3) The maturing principal payments from securities purchased under the PEPP will be reinvested until at least the end of 2022. (4) Net purchases under the asset purchase programme (APP) will continue at a monthly pace of €20 billion, together with the purchases under the additional €120 billion temporary envelope until the end of the year. (5) Reinvestments of the principal payments from maturing securities purchased under the APP will continue.
16 July 2020	(1) The Governing Council will continue its purchases under the pandemic emergency purchase programme (PEPP) with a total envelope of €1,350 billion. (2) Net purchases under the asset purchase programme (APP) will continue at a monthly pace of €20 billion, together with the purchases under the additional €120 billion temporary envelope until the end of the year. (3) The Governing Council will also continue to provide ample liquidity through its refinancing operations.

10 September 2020	(1) The Governing Council will continue its purchases under the pandemic emergency purchase programme (PEPP) with a total envelope of €1,350 billion. (2) Net purchases under the asset purchase programme (APP) will continue at a monthly pace of €20 billion, together with the purchases under the additional €120 billion temporary envelope until the end of the year. (3) The Governing Council will also continue to provide ample liquidity through its refinancing operations.
29 October 2020	(1) The Governing Council will continue its purchases under the pandemic emergency purchase programme (PEPP) with a total envelope of €1,350 billion. (2) Net purchases under the asset purchase programme (APP) will continue at a monthly pace of €20 billion, together with the purchases under the additional €120 billion temporary envelope until the end of the year. (3) The Governing Council will also continue to provide ample liquidity through its refinancing operations.
10 December 2020	(1) The Governing Council decided to increase the envelope of the pandemic emergency purchase programme (PEPP) by €500 billion to a total of €1,850 billion. (2) The Governing Council decided to further recalibrate the conditions of the third series of targeted longer-term refinancing operations (TLTRO III). (3) The Governing Council decided to extend to June 2022 the duration of the set of collateral easing measures adopted by the Governing Council on 7 and 22 April 2020. (4) The Governing Council also decided to offer four additional pandemic emergency longer-term refinancing operations (PELTROs) in 2021, which will continue to provide an effective liquidity backstop. (5) Net purchases under the asset purchase programme (APP) will continue at a monthly pace of €20 billion.
21 January 2021	(1) The Governing Council will continue the purchases under the pandemic emergency purchase programme (PEPP) with a total envelope of €1,850 billion. (2) Net purchases under the asset purchase programme (APP) will continue at a monthly pace of €20 billion. (3) The Governing Council will continue to provide ample liquidity through its refinancing operations.
11 March 2021	(1) The Governing Council will continue to conduct net asset purchases under the pandemic emergency purchase programme (PEPP) (2) Net purchases under the asset purchase programme (APP) will continue at a monthly pace of €20 billion. (3)The Governing Council will continue to provide ample liquidity through its refinancing operations.

Matteo Foglia and Vincenzo Pacelli

THE BEHAVIOUR OF SYSTEMIC RISK AND MONETARY POLICY STANCE: WHAT IS THE LINK? A WAVELET EVIDENCE[*†]

ABSTRACT

Il lavoro analizza la relazione tra il rischio sistemico e la politica monetaria della Banche centrale europee (BCE) per otto paesi dell'Eurozona. A tal fine, abbiamo applicato l'analisi wavelet. La suddetta metodologia ci consente di ottenere informazioni utili sulle correlazioni dinamiche nel tempo e sulle diverse frequenze temporali Due principali risultati emergono dal nostro studio. Da un lato, troviamo che nel breve periodo un elevato livello di rischio sistemico non implica interventi di politica monetaria. Dall'altro, abbiamo riscontrato che nel lungo periodo (un anno) la BCE segue l'approccio "lean against the wind", ovvero interviene per ridurre il rischio sistemico.

The article analyses the co-movement between systemic risk and the European Central Banks' (ECB) monetary policy stance for eight Eurozone countries. To this end, we applied wavelets analysis. This methodology allows us to obtain helpful information on dynamic correlations over time and different temporal frequencies. Our study achieves two main results. On the one hand, we find that a high level of systemic risk does not imply ECB interventions in the short run. On the other, we found that the ECB follows the "leaning against the wind" approach in the long run, i.e. it intervenes to reduce risk. Our paper highlights how the ECB's response to the systemic risk is delayed.

KEYWORD

Rischio sistemico - Politica monetaria - analisi wavelet

Systemic risk -Monetary policy - wavelet analysis

SUMMARY: 1. Introduction- 2. Methodology - 2. (Segue:) The systemic risk measure - 2. (Segue:) The Wavelet methodology – 3 Data overview- 4. Empirical results – 5. Conclusion

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1. The various financial crises that have followed one another in recent years (such as the Great Recession or the sovereign debt crisis) have triggered a change in monetary policy behaviour globally by altering the standard analysis of monetary policy. In fact, the movement of interbank rates (federal funds rate [FRB], or the Marginal operation [ECB]) used as the primary policy instrument has reached its zero lower bound. This made the standard conduct of monetary policy somewhat ineffective, stimulating the increasing use of the so-called unconventional policy.[1,2]

On the other hand, maintaining financial stability has become a major concern for policymakers. In today's highly volatile and uncertain environment, the ability of central banks to be concerned about financial stability assumes a key role. Indeed, the adverse effects caused by the pandemic (economic recession), most recently the Russia-Ukraine war, underline the need to safeguard financial stability, both at the country and global level.

A still debated question is whether central banks should follow the 'leaning against the wind' or the 'modified Jackson Hole consensus'. The first holds that central banks should use a monetary stance to manage financial imbalances; the second argues that central banks should only focus on price stability[3].

In this research, we aim to investigate the effect of Eurozone monetary policy on systemic risk. We want to examine whether both policy approaches interact between them and what is their impact on financial imbalances. In particular, we assess the dynamic effects of monetary policy on systemic risk in 8 Eurozone countries (Austria, France, Germany, Greece, Ireland, Italy, the Netherland and Spain).

Our empirical investigation is structured in three parts. First, we estimate the $\Delta CoVaR$ per country, a systemic risk index that can capture spillover effects across institutions, i.e., the ability of each institution to spread risk to the rest of the system. Second, to use a monetary policy measure that considers conventional and unconventional policies, we compute the shadow rate[4]. This measure allows us to synthesise information from policies and market expectations in today's Zero Lower Bound era[5]. Finally, we apply wavelet analysis, which allows us to capture the relationship between systemic risk and monetary policy in a dynamic manner.

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[1] See Kabundi, A., & De Simone, F. N. (2020). *Monetary policy and systemic risk-taking in the euro area banking sector. Economic Modelling, 91, 736-758.*

[2] See Faia, E., & Karau, S. (2021). *Systemic Bank Risk and Monetary Policy. International Journal of Central Banking*

[3] See Smets, F. (2018). *Financial stability and monetary policy: How closely interlinked?. 35th issue (June 2014) of the International Journal of Central Banking.*

[4] See Wu, J. C., & Xia, F. D. (2016). *Measuring the macroeconomic impact of monetary policy at the zero lower bound. Journal of Money, Credit and Banking, 48(2-3), 253-291.*

[5] L. Krippner, *Zero lower bound term structure modeling: A practitioner's guide.* Springer 2015

We contribute to the debate on the relationship between financial imbalances and monetary policy in several ways. Although several studies have analysed the topic[6,7,8], we are the first to investigate this relationship at the country level. Studying this nexus at the country level, distinguishing between core and non-core countries, allows us to investigate the cross-country and cross-temporal heterogeneity of the relationship. Investigating such heterogeneity is crucial in the Eurozone Monetary Union (EMU) context, where a single monetary policy (one size fits all) compares with different financial systems. Second, thanks to wavelet analysis, we can quantify the impact at the dynamic and frequency level and investigate the time-varying property of the relationship. Compared to the existing literature, this methodology allows us to analyse the short- and long-term correlation (dynamically) between different frequency levels. This distinction is essential to understanding how systemic risk and monetary policy influence each other.

The rest of the paper proceeds as follows. Section 2 describes the $\Delta CoVaR$ methodology and the wavelet model. Section 3 presents the data used in the analysis. Section 4 shows the empirical results, while Section 5 reports the conclusions.

2.1 We build a systemic risk country index by computing the $\Delta CoVaR$ developed by Adrian and Brunnermeier[9]. This measure is an extension of the value-at-risk (VaR) approach, and is able to capture the conditional risk, i.e., the risk relationship (spillover effect) between financial institutions.

Formally, the $CoVaR$ is the maximum loss that a company can incur, at a defined probability level equal to p, and over a time horizon t. The $CoVaR$ can be expressed as the VaR of the financial system conditioned by the occurrence of a specific stress event.

Hence, defined the VaR of institution i as follows:

$$P(R^i \leq VaR_q^i) = q \qquad (1.1)$$

we can compute the $CoVaR$ as:

$$P(R^s \leq CoVaR_q^{s|i} \mid R^i = VaR_q^i) = q \qquad (1.2)$$

where R^i and R^s is the stock returns of firm i and of the financial system, respectively, q denotes the confidence level of probability. We set the quantile level q

[6] See Colletaz, G., Levieuge, G., & Popescu, A. (2018). *Monetary policy and long-run systemic risk-taking. Journal of Economic Dynamics and Control, 86, 165-184.*

[7] See Foglia, M., Addi, A., Wang, G. J., & Angelini, E. (2022). *Bearish Vs Bullish risk network: A Eurozone financial system analysis. Journal of International Financial Markets, Institutions and Money, 77, 101522.*

[8] See Faia, E., & Karau, S. (2021). *Systemic Bank Risk and Monetary Policy. International Journal of Central Banking*

[9] See Adrian T., & Brunnermeier, M. K. (2016). *CoVaR. The American Economic Review, 106(7), 1705.*

= 5%, in order to study the downside risk. Finally, we can calculate the $\Delta CoVaR$ as follows:

$$\Delta CoVaR_q^i = CoVaR_q^{s|R^i = VaR_q} - CoVaR_q^{s|R^i = VaR_{0.5}} \quad (1.3)$$

where $CoVaR_q^{s|R^i = VaR_{0.5}}$ is the CoVaR estimated in normal times (q = 0.5). The CoVaR and the conditional CoVaR is estimated via quantile regressions.

2.2 Wavelet analysis has several interesting features. First, it is a method that allows the decomposition of time-series variables in both the time and frequency domains. This feature will enable us to understand how variables may interact differently on different time scales. Second, the methodology can determine discontinuities in the system. This allows us to identify points of temporal regime shifts. For example, how shocks within the system can be short or long-run.

To study the relationship between systemic risk ($\Delta CoVaR$) and monetary policy (shadow rate) in the time and frequency domain, in this paper, we use continuous wavelet transforms and the wavelet coherence approach.

2.2.1 The starting point of wavelet methodology is to identify the mother wavelet, which is given by:

$$\psi_{\tau,s}(t) = \frac{1}{\sqrt{s}}\psi\left(\frac{t-\tau}{s}\right) \quad (1.4)$$

where τ is the location parameter, s denotes the scale coefficient, while $\frac{1}{\sqrt{s}}\psi$ is a normalisation constant that ensure the unit variance of the model.

Once the mother wavelet is established, we can define the continuous wavelet transform as follows:

$$W_x(s) = \int_{-\infty}^{\infty} x(t)\frac{1}{\sqrt{s}}\psi^*\left(\frac{t}{s}\right) \quad (1.5)$$

where * shows the complex conjugate. This measure allows us to study the temporal evolution of frequency content.

2.2.2 The wavelet coherence allows us to specify and investigate the dependence between systemic risk and monetary policy stance. We can define the cross-wavelet (CW) as follows:

$$W_n^{XY}(s) = W_n^X(s)W_n^Y{}^*(s) \quad (1.6)$$

where $X(t)$ and $Y(t)$ are two time series variables (shadow rate and $\Delta CoVaR$ in our case), while $W_n^X(s)$ and $W_n^Y(s)$ shows the continuous wavelet transforms. The CW captures the covariance contribution in the time-frequency space.

In order to study the co-movement dynamic over time and across frequency, we follow Torrence and Webster10, and we compute the wavelet coherence coefficient, i.e.,

$$R_n^2(s) = \frac{|(s^{-1}W_n^{XY}(s))|^2}{(s^{-1}|W_n^X(s)|^2)(s^{-1}|W_n^Y(s))|^2)} \qquad (1.7)$$

where s denotes the smoothing mechanism. The wavelet squared coherence ($R_n^2(s)$) value is included between zero and one, i.e., a value near zero indicates no correlation, while a value proximity to one suggests strong dependence. Finally, we obtain the statistical significance of the wavelet coherence and cross-spectra employing a Monte Carlo simulation

2.2.3 To study the frequency dynamic lead-lag correlation, we use the wavelet coherence phase differences. We can define the wavelet coherence phase differences as follows:

$$\rho_{xy}(s) = tan^{-1}\left(\frac{\Im(s^{-1}W_n^{XY}(s)}{\Re(s^{-1}W_n^{XY}(s)}\right) \qquad (1.8)$$

where $\Im$ is the imaginary parts while $\Re$ is the real part of the smooth power spectrum. The phase correlations are expressed by arrows. In particular, if the arrows point to the right (left) the two-time series are in phase (anti-phase), i.e., there is a positive (negative) correlation. On the other hand, if the arrows point up (down) the first (second) variable leads (implies) to the second (first) one. This representation can allow us to investigate the lead-lag relationship.

3. For each country, we use the constituents of the countries' DS Financials Index of Datastream database. The index comprises a multiplicity of financial institutions of various kinds (banks, insurance companies, financial diversified, real estate). This allows us to construct an overall global systemic risk market capitalization-weighted index of the financial system for each country. Our sample spans from January 2006 to December 2021.

To calculate the $\Delta CoVaR_q^i$ we use the daily stock price returns for each firm belonging to the DS Financials Index at a country level and the stock return of the EURO STOXX 50 index representing the Eurozone financial market. Finally, to capture the macro environment, we follow Adrian and Brunnermeier and Foglia and Angelini[11] and we include the following state variables: i) the VDAX, ii) the short-term spread (difference between 3-month Euribor and 3-month German government bond

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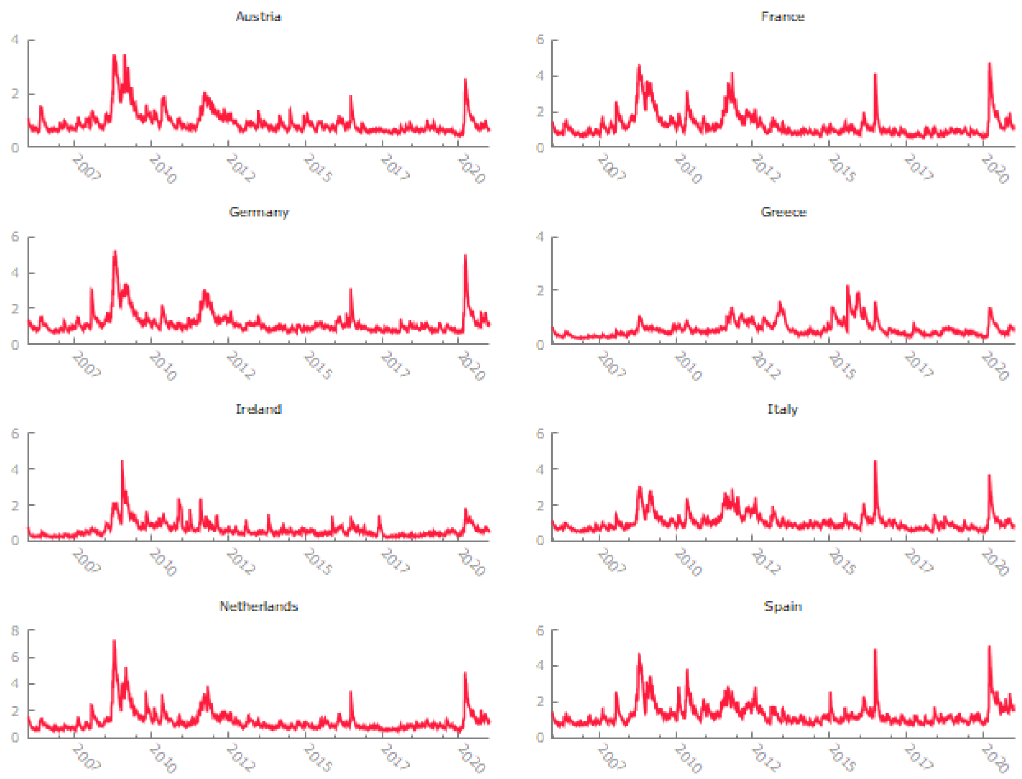
[10] See Torrence, C., & Webster, P. J. (1999). *Interdecadal changes in the ENSO–monsoon system. Journal of climate, 12(8), 2679-2690.*

[11] See Foglia, M., & Angelini, E. (2020). *From me to you: measuring connectedness between Eurozone financial institutions. Research in International Business and Finance, 54, 101238.*

yield), and iii) the slope curve (difference between the 3-month and 10-years Germany bond yield).

Figure 1 shows the evolution of $\Delta CoVaR_q^i$ for each country. We can observe several picks that correspond to the main financial event that affects the Eurozone. We see how the U.S. financial crisis (2007-2009), the sovereign debt crisis (2010-12), the Brexit (2016-17) and finally, the COVID-19 (2020) pandemic led to a significant increase in system risk. Moreover, the dynamics of $\Delta CoVaR_q^i$ show that the so-called core countries (Germany, France, the Netherlands, and Austria), are more affected by the global financial crisis of 2008. On the other hand, the non-core countries (Italy, Spain, Greece) show a high level of risk both during 2008 and during the sovereign debt crisis (2012-13).

Figure 1. The dynamic of $\Delta CoVaR_q^i$



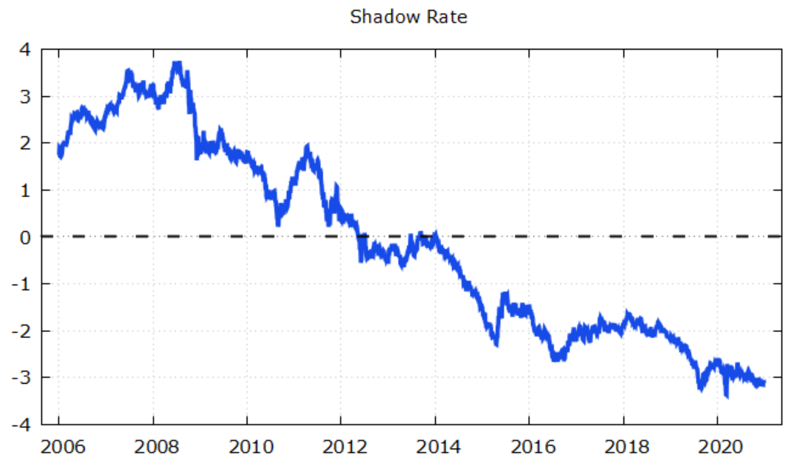
To have a unique measure of ECB monetary policy, we estimate by factor analysis the shadow rate index from the ECB yield curve. The great use in the literature of this measure[12] is dictated by the fact that the index manages to capture both conventional and unconventional monetary policy. In figure 2, we show the evolution of the shadow

[12] L. Krippner, Zero lower bound term structure modeling: A practitioner's guide. Springer 2015

rate. A value greater than zero indicates a restrictive policy, while a lower value corresponds to an expansionary monetary policy.

As we can note, since 2015, the index has been less than zero, suggesting how the ECB has followed an expansionary policy, such as the Single Supervisory Mechanism (SSM, November 2014), the ABS purchase programme (2015), the new long-term refinancing operations (September 2019), the new Pandemic Emergency Purchase Programme (March 2020), as well as the credit line of the European Stability Mechanism (ESM).

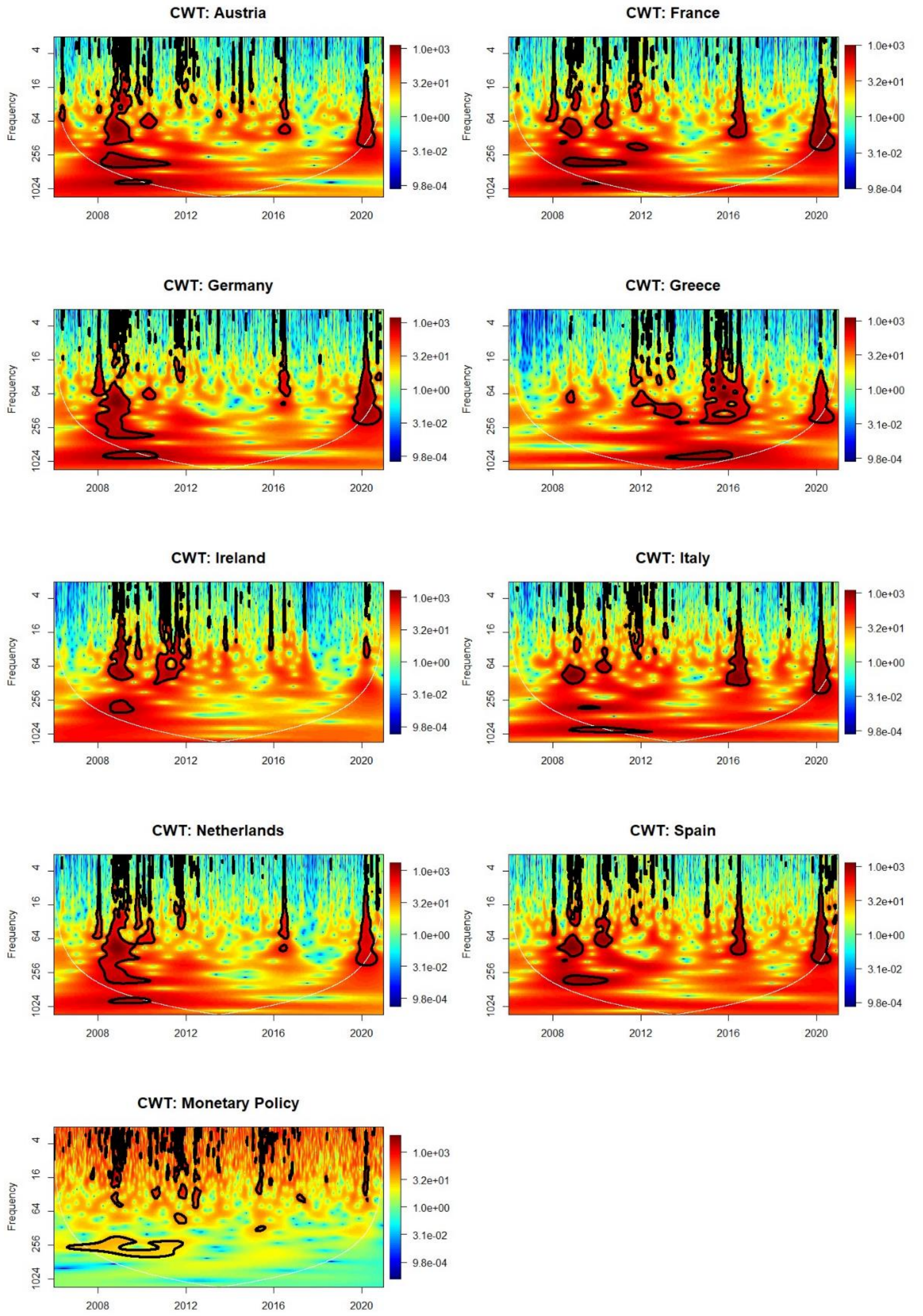
Figure 2. The shadow rate behaviour



4. In Figure 3, we plot the continuous wavelet transform (CWT). CWTs show systemic risk and shadow rate dynamics in time and frequency bands. The CWT is a useful tool for determining the specific parts in the time-frequency domain where unexpected changes (shocks) occur in the time series dynamics under observation, i.e., the systemic risk and monetary policy.

The vertical axis shows the frequencies component, while the horizontal axis shows the time component. The frequency component ranges from 0 days to 1024 days (approximately four market years). Regions of 5% significance (as estimated by Monte Carlo simulations) are plotted by shaded contours. The colder (warmer) colour indicates the less (more) intense dependencies in the time-frequency domain. Finally, the curved line represents the cone of influence. The latter shows the area affected by edge effects.

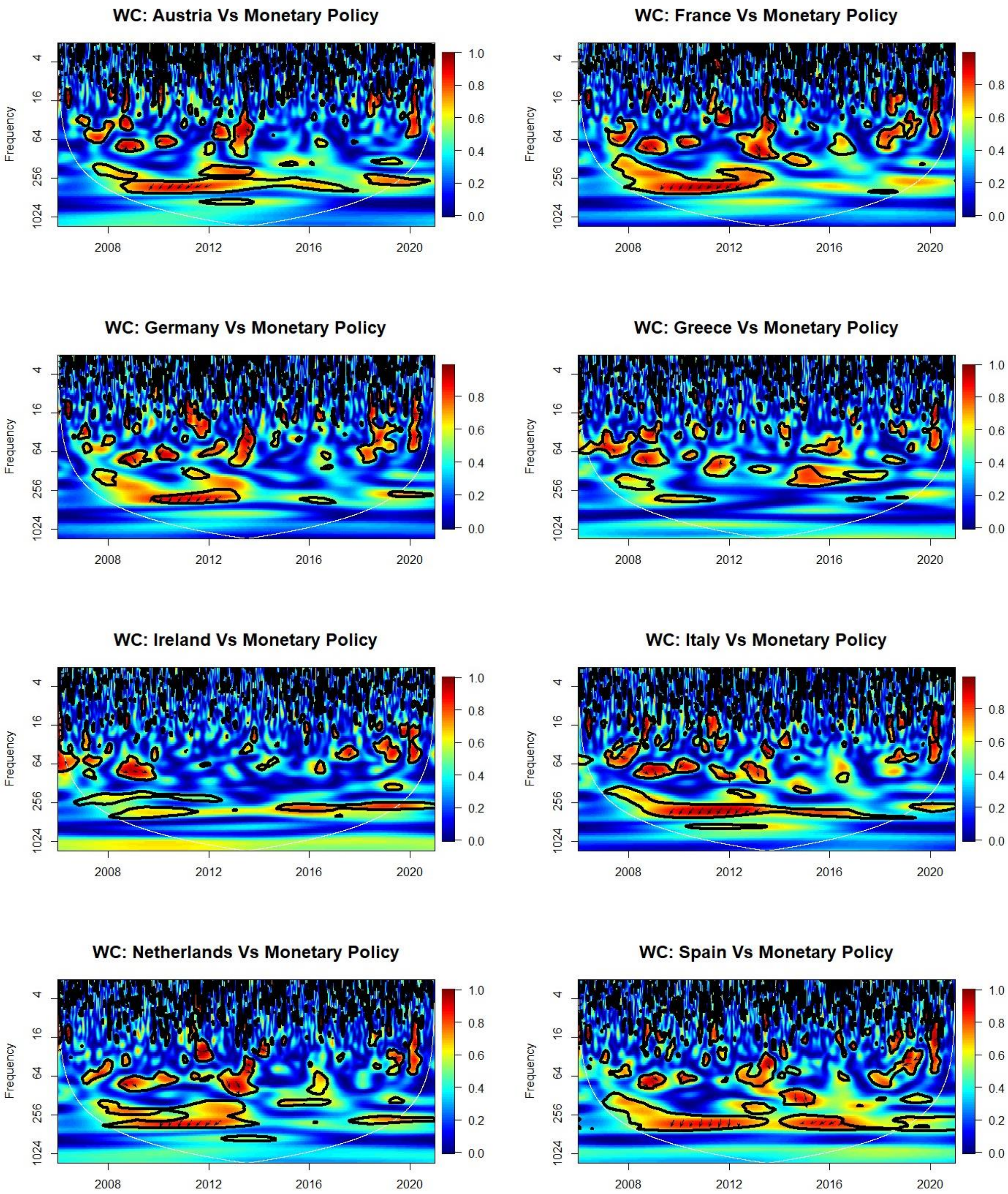
Figure 3. Continuous wavelet transforms



As we can observe from the figures, most countries reacted to shocks on scales slightly larger than one year. We can keep several islands of high volatility in both the medium and long term. In fact, we can distinguish four phases that affected the systemic risk of the Eurozone: i) U.S. financial crisis, 2) the sovereign-debt crisis, 3) the Brexit effect and NPL problem and finally, 4) the COVID-19 pandemic. Interesting is the case of Greece. The Figure shows a very different representation from the other countries. The highest significance level is in the middle of the diagram, suggesting Greece's severe financial imbalances triggered the sovereign debt crisis. In addition, we can observe a large shadow around 2015-2016 coinciding with national elections and thus with the break-in negotiations with the Troika. Focusing on the CWT of the shadow rate, we can see a significant spot from 2007 until 2012 as evidence of the large interest rate manoeuvres in that period. Overall, more power emerged at intermediate (about 4 months) and higher (one year) frequencies than at lower frequencies.

In order to investigate the interdependence i.e., the co-movement between systemic risk and monetary policy, in Figure 4, we report the wavelet coherence analysis diagrams for each pair of variables and for each country. The study of the wavelet coherence diagrams allows us to investigate the direction of the relationship between these variables and verify: i) what relationship exists between the variables (positive or negative correlation) and ii) which variable implies the other. Also in this figure, the time dimension is shown on the x-axis, while the frequency is shown on the y-axis. The black outline indicates the 5% significance level, while the colour range indicates the degree of dependence. Colours tending towards red correspond to the area with greater co-movements, while colours tending towards blue identify areas with less dependence. Arrows to the right or left indicate the direction of the correlation: if the arrow is to the right we have a positive relationship (in phase), while an arrow to the left indicates a negative relationship (counter-phase). On the other hand, arrows pointing right up or left down (↗ ↙) indicate that systemic risk ($\Delta CoVaR$) drives monetary policy (shadow rate), while arrows pointing right down or left up (↘ ↖) suggest that monetary policy drives systemic risk. Finally, arrows pointing upwards (downwards) (↑↓) indicate that systemic risk is leading (lagging).

Figure 4. Wavelet coherence



The graph shows several periods of high (red colour) significant dependence (black outline), especially around the U.S. financial crisis, the sovereign debt crisis, the Brexit and the COVID-19 outbreak. We note how systemic risk and monetary policy are weakly correlated at lower frequencies. This weakness persists over most of the period. However, the figure shows how dependence increased even at lower frequencies, especially after the onset of the COVID-19 pandemic. On the other hand, we can observe how the significant islands strongly depend on the medium (64 days) and long term (256 days).

A visual inspection of the graphs reveals surprising facts. Focusing our attention on the islands on the average frequencies (64 days), we notice how monetary policy drives systemic risk, both after 2008 and during 2012-13. This result means that the various interventions implemented by the ECB in response to the Great Recession and the Eurozone crisis affected systemic risk. Furthermore, the arrow to the right means that the relationship is in phase, hence positive. An expansionary policy, i.e. a reduction in the shadow rate, causes a decrease in systemic risk. On the other hand, a restrictive policy (increase in shadow rate) will increase it.

It is well to bear in mind that the Interventions were not dictated by the high levels of systemic risk. In fact, the wavelet coherence analysis plots show a significant directional relationship between policy and risk, but not in the other direction. This result confirms the studies by Colletaz *et al*[13]., and Foglia *et al*[14]. The authors show how monetary policy affects risk but how the latter does not influence the policy of the European Central Bank. However, the relationship changes completely in the long-run frequencies (256 days). In this case, systemic risk implies monetary policy intervention. This result makes a significant contribution to the literature. Contrary to the literature, we show for the first time how the ECB intervened to reduce the high levels of stress in the financial system. That is, the ECB followed a strategy of 'leaning against the wind'. The figure shows a negative relationship here, perfectly in line with this strategy. A higher level of systemic risk is followed by an expansionary policy (lower shadow rate), while lower systemic risk implies a restrictive policy (higher shadow rate).

Inspection of the graphs revealed interesting results. First, we can observe a significant co-movement of risk and monetary policy during the major events that affected the euro area countries. A common nexus picture emerges from the analysis. Second, we find little dependence heterogeneity between core (Austria, Germany, France, the Netherlands) and non-core (Ireland, Italy, Greece, Spain) countries. This also suggests that a one-fits-all monetary policy can have very homogeneous effects among the euro countries. The only country with a different co-movement is Greece, where the islands of significance are arranged more in the medium term. This result

[13] See Colletaz, G., Levieuge, G., & Popescu, A. (2018). *Monetary policy and long-run systemic risk-taking. Journal of Economic Dynamics and Control, 86, 165-184.*
[14] See Foglia, M., Addi, A., Wang, G. J., & Angelini, E. (2022). *Bearish Vs Bullish risk network: A Eurozone financial system analysis. Journal of International Financial Markets, Institutions and Money, 77, 101522.*

reveals how ECB policies have not been able to avert the effects of the Greek systemic crisis[15].

5. This study uses the wavelet transform method to explore the co-movement between systemic risk ($\Delta CoVaR$) and ECB monetary policy. This approach allows us to examine dynamic lead-lag linkages in the time-frequency domain and investigate the causal relationship. Our results provide several pieces of evidence. First, we found a significant co-movement between systemic risk and monetary policy during the two financial crises (U.S. and Eurozone) and during the pandemic outbreak. Second, we provide evidence of little heterogeneity of dependence across countries (except for Greece). Hence, also a one fit size policy is able to smooth the stock market turbulences. Third, we find fresh evidence that the ECB intervened to reduce systemic risk, but with a long-run effect. This result significantly contributes to the literature, highlighting the ECB's ability to influence financial turmoil.

Overall, our findings indicate that changes in monetary policy stance are not harmless to the level of systemic risk. However, the analysis highlights how interventions suffer from implementation lags and how these policies could not avert the effects of the Greek systemic crisis. A key message of this paper is that the ECB's response to the risk of contagion was not timely, i.e., the analysis shows how the effects impacted only on the long frequency. This is perfectly in line with Petrakis et al[16]., who found that the existence of a time delay between the announcement and the implementation of monetary measures.

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[15] Clancy, D., Gabriele, C., & Žigraiová, D. (2022). *Sovereign bond market spillovers from crisis-time developments in Greece. Journal of International Financial Markets, Institutions and Money, 101558.*

[16] Petrakis, N., Lemonakis, C., Floros, C., & Zopounidis, C. (2022*). Eurozone Stock Market Reaction to Monetary Policy Interventions and Other Covariates. Journal of Risk and Financial Management, 15(2), 56.*

Andrea Delle Foglie, Renato Aprile and Ida Claudia Panetta

SUKUK AND GREEN BONDS' ROLE IN GLOBAL MACRO PORTFOLIO DIVERSIFICATION: EVIDENCE FROM COVID-19 CRISIS*

ABSTRACT

La crisi di Covid-19 ha risvegliato e rafforzato alcuni temi di tendenza legati alla gestione del rischio di portafoglio e alla mitigazione del rischio sistemico. I principali gestori di portafoglio hanno iniziato a testare nuove strategie flessibili di tipo *multi-asset* (anche dette strategie Global Macro) basate sull'interpretazione di condizioni macroeconomiche di ampia portata. Queste strategie prevedono, nella costruzione dell'*asset allocation*, l'utilizzo di posizioni lunghe e corte in azioni, obbligazioni, materie prime, ecc. Questo lavoro vuole testare il contributo corretto per il rischio dei Sukuk (obbligazioni islamiche) e dei Green Bond come strumenti alternativi agli strumenti di reddito fisso convenzionali, considerando il periodo pre e post Covid-19. L'asset allocation è stata progettata seguendo i fondamenti del Global Macro e risolvendo un problema di ottimizzazione *risk-parity* utilizzando un algoritmo MATLAB™ appositamente sviluppato. I risultati forniranno approfondimenti sul potere di copertura e di rifugio dei Sukuk e dei Green Bond, contribuendo all'ampliamento della letteratura sulla gestione del rischio di portafoglio e allo sviluppo di un'asset allocation alternativa funzionale ai fondamenti del Global Macro.

Covid-19 distress has awakened and reinforced some long-standing trending topics related to portfolio risk management and systemic risk mitigation. Portfolio managers have started to test flexible multi-asset portfolio strategies (Global Macro Strategies) based on the interpretation of large macroeconomic conditions, including the asset allocations of long and short positions in equities, bonds, commodities, etc. This study aims to test the risk-adjusted contribution of Sukuk (Islamic bonds) and Green Bonds as alternative instruments compared to conventional fixed-income, covering the last Covid-19 crisis. The asset allocation is designed following the fundamentals of Global Macro and solving a risk-parity optimisation problem using a specifically developed MATLAB™ algorithm. The findings will provide insights into the testing hedge and safe-haven power of Sukuk and Green Bonds, contributing to the widening literature on portfolio risk management and developing an alternative asset allocation functional with Global Macro fundamentals.

KEYWORDS

Portfolio Management – Sustainable Finance – Islamic Finance

SUMMARY: 1. Introduction and Background. – 2. Methodology: the Risk Parity Optimization Problem. - 3. Data and Sample Selection. – 4. Empirical Results: Descriptive Statistics and Correlations

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– 5. Empirical Results: The Conventional GM Portfolio ERC Optimisation - 6. Empirical Results: The *Alternative GM Portfolio* ERC Optimisation - 7. Conclusions and Further Remark

1. The impact of Covid-19 and change in macroeconomic scenario is felt beyond the health sector and severely affected stocks and the whole financial markets more generally. Morgan Stanley Outlook in 2021 has predicted the overheating of the economy *"as economic imbalances wrought by the pandemic begin to ease, investors could be in for hotter-than-expected growth and inflation"*[1]. The vulnerability of financial markets, due to firms' squeezing profits, credit crunch, energy crisis, and geopolitical and economic uncertainty, the vulnerability of financial markets contribute to increased systemic risk. According to So et al. in 2022[2], systemic risk in financial markets may occur due to a simultaneous fall in the price of most or all stocks in the market caused by an event affecting one or more company or business sectors. Financial system globalisation and interconnection have emphasised this phenomenon, facilitating systemic risk propagation. In this evolving scenario and increasing challenges, investors and portfolio managers have renewed their attention to alternative investments, which could offer significant diversification for the conventional markets and portfolios severely affected by this uncertainty, trying to reduce the systemic risk sword of Damocles[3].

For more than ten years, the world's stock markets have seen record growth since the world's major central banks have jointly exercised unprecedented expansionary monetary policy producing record-low bond yields and record-high equity prices, almost forgetting portfolio risks and volatility. During these calm periods, investors allocate more to stocks and high volatility assets to achieve higher returns and switch to fixed-income asset classes during turbulent markets to reduce their portfolio aggregate risk. Thus, as in any financial downturns or market stress, as for the Covid-19 crisis, investors and asset managers are looking for uncorrelated or negatively correlated assets or portfolio strategies, which could provide safe-haven power and hedging benefits, risk-diversification, and maximum drawdown mitigation. In this regard, academics and practitioners have recently started showing particular interest in sustainable and ethical finance, green investments and non-conventional markets such as the Islamic Financial one[4]. During these times occurs a renewed attention to alternative strategies that fit with the "Global Macro" description. Global Macro is a flexible multi-asset portfolio strategy based on the interpretation of large

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[1] See Morgan Stanley. (2020). *2021 Global Strategy Outlook: Keep Faith in the Recovery*.
[2] See So, M.K.P., Mak, A.S.W., Chu, A.M.Y. (2022). *Assessing systemic risk in financial markets using dynamic topic networks. Sci Rep 12, 2668.*
[3] See Naeem, M.A., Rabbani, M.R., Karim, S., Billah, S.M. (2021). *Religion vs ethics: hedge and safe haven properties of Sukuk and green bonds for stock markets pre- and during COVID-19.*
[4] See Yarovaya, L., Elsayed, A.H. (2021). *Determinants of spillovers between islamic and conventional financial markets: exploring the safe haven assets during the COVID-19 pandemic*, *Finance Research Letters, 43.*

macroeconomic conditions, mainly adopted by hedge fund managers. These strategies include the asset allocations of long and short positions in equities, bonds, commodities, currencies etc. Global Macro generally has outperformed other strategies, resulting in positive returns than other strategies that have been severely challenged[5]. Notably, it benefits from sustained increased volatility in currencies, interest rates, commodities and equities, and it has a low correlation to stocks. These reasons fit together with boundary conditions that occur during crisis periods.

Looking at the mentioned alternative asset classes, literature provides evidence about green bonds' diversification power and hedge capability under unfavourable market circumstances[6]. Green bonds are similar to conventional bonds, and they are used to finance environmentally friendly and green projects satisfying the demand for clean and renewable energy[7]. Similarly, Sukuk, also called Islamic Bond, Islamic Stock or Islamic debt securities, is an Islamic Financial instrument with similar properties to conventional bonds. It is based on the asset-backed rules of securitisation or conventional covered bond s*hariah* compliant Sukuk can offer diversification opportunities to conventional portfolios since they have a low correlation with conventional bonds, particularly during turmoil periods[8]. Thus, the question is related to the possibility of integrating the fixed-income component of the asset allocation with these alternative instruments.

Finally, this paper contributes to the literature on portfolio systemic risk management, examining the hedge and safe-haven properties of alternative asset classes such as Sukuk and green bonds for the conventional portfolio strategies during financial market turmoil as in the Covid-19 crisis. According to the literature previously mentioned, investors use the strategy of hedging and diversification to combat the adverse impact of the stock market downturn on their investment portfolios, trying to mitigate the systemic risk associated with exogenous events such as Covid-19. Notably, this paper does not seek to merely explore the best strategies or financial assets performing during market crises. Following the integration approach, Delle Foglie and Panetta[9] proposed, this paper aims to consider the possibility of including alternative asset classes to the conventional portfolio allocation to increase diversification, mitigate risks and reduce maximum drawdown. In this way, is it possible to continue the aim of Global Macro investors, trying to build portfolios that perform well across different economic scenarios. Thus, in this paper, we build an Alternative Global Macro

[5] See Casano, J. (2010). *Global macro Hegde fund investing: an overview of the strategy,* NEPC, Boston.
[6] See Hachenberg, B., Schiereck, D. (2018). *Are green bonds priced differently from conventional bonds?, Journal of Asset Management, 19 (6).*
[7] See Naeem, M.A., Farid, S., Ferrer, R. and Shahzad, S.J.H. (2021). *Comparative efficiency of green and conventional bonds pre-and during COVID-19: an asymmetric multifractal detrended fluctuation analysis, Energy Policy, 153.*
[8] See Paltrinieri, A., Hassan, M.K., Bahoo, S., Khanc, A.(2019).*A bibliometric review of sukuk literature*.
[9] See Delle Foglie, A., Panetta, I.C. (2020). *Islamic stock market versus conventional: Are islamic investing a 'Safe Haven'for investors? A systematic literature review*.

(GM) Portfolio and test its risk-adjusted performance compared with a conventional Global Macro strategy. To build the asset allocation, this paper follows the literature strands concerning the Risk Parity model[10] [11] [12], often used by fund managers as an asset allocation selection criteria.

The remainder of this paper is organised as follows. Section 2 provides the research design, focusing on empirical properties of the risk parity heuristic approach. The optimisation problem of the risk parity is solved using the specifically designed MATLAB algorithm. Section 3 presents and debates the data, and Sections 4, 5 and 6 present descriptive statistics, correlations and empirical results of the conventional and alternative portfolio. Finally, the main conclusions and further remarks are disclosed in Section 7.

2. The development of risk parity and risk budgeting techniques has marked an important milestone in portfolio risk management, rewriting Markovitz's Modern Portfolio Theory and changing market players' mindsets[13]. In addition, after the dark years (2008-2011) and various market stresses in recent years (2015-2016 Stock Market Sell-Off, or Covid-19 Market Crash), the Equal Risk Contribution (ERC) has been very popular and significantly impacted the asset management industry. For instance, in 2011, Bridgewater Associates, the world's biggest hedge fund company, has first opened the doors to this strategy by publishing a famous milestone paper, "Risk Parity is about balance", imaging *"to design a portfolio based on a fundamental understanding of the environmental sensitivities inherent in the pricing structure of asset classes"*[14]. The risk parity approach in ERC seems to provide stability to the asset allocation since it does not consider any returns in the weight distribution but the risk contribution of a single component as the Marginal Risk Contribution (a share of the total portfolio risk contribution). Thus, it appears more robust than the *Markovitzian*

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[10] See Quian, E. (2005) *Risk Parity Portfolios: Efficient Portfolios through True Diversification, Panagora Asset Management, Boston.*
[11] See Lee, T., Spellar, A., Bouchey, P. (2013).*Understanding Risk Parity – The Clifton Group, Division of Parametric Portfolio Associates.*
[12] See Roncalli, T. (2013). *Introduction to Risk Parity and Budgeting*.
[13] G.C. Hallen, *The Risk Parity Approach to Asset Allocation*, Callan Investment Research Institute, 2010.
[14] Bridgewater Associates, *Risk Parity is about balance*, White Paper Bridgewater Ass, 2011.

mean-variance optimised portfolios[15] [16] [17] [18] [19] [20] [21] [22] [23] [24]. According to Richard and Roncalli (2019), we defined a portfolio *X = (x1; x2; …; xn)* of n risky assets, assuming no possibility of leverage, short selling, minimum investment weight, sector neutrality or liquidity thresholds. We assume the $MRC_i(x) = \frac{(\Omega x)_t}{\sqrt{x^T \Omega x}}$ and the $TRC_i(x) = x_i \frac{(\Omega x)_t}{\sqrt{x^T \Omega x}}$, where *Ω* is the covariance matrix. Since the ERC aims to build a risk-balanced portfolio considering the asset allocation in terms of risk contribution (risk budgeting), we consider risk budget *b*, and the vector of risk in the percentage of the total risk $b = (b_1, b_2, \dots, b_n)$, where $b_i = b_j = 1/n$, the $TRC_i(x) = TRC_j(x)$ and the $x_i \frac{(\Omega x)_t}{\sqrt{x^T \Omega x}} = x_j \frac{(\Omega x)_t}{\sqrt{x^T}}$ so it is easy to show that the

$$\sum_{i=1}^{n} TRC(x) = nTRC_i(x) \text{ and the } TRC_i(x) = \frac{\sigma(x)}{n}. \quad (1)$$

In order to find the solution, the risk parity can be solved as the following optimisation problem:

$$X = arg\ min\ f(x) \quad (2)$$

$$where\ f(x) = \sum_{i=1}^{n} \sum_{i=1}^{n} (TRC_i(x) - TRC_j(x))^2$$

$$where\ f(x) = \sum_{i=1}^{n} \sum_{i=1}^{n} (x_i\ (\Omega x)_i - x_i\ (\Omega x)_j)^2, \sum_{i=1}^{n} x_i = 1\ and\ x \geq 0$$

Considering the Euler decomposition of the portfolio risk measure

$$X = arg\ min \sum_{i=1}^{n} (x_i\ (\Omega x)_i - \frac{\sigma_p(x)}{n})^2 \quad (3)$$

[15] J.C. Richard, T. Roncalli, *Constrained Risk Budgeting Portfolios: Theory, Algorithms, Applications & Puzzles*, 2019.
[16] M.R. Anderson, S.W. Bianchi, L. Goldberg, *Will My Risk Parity Strategy Outperform?*, Financial Analysts Journal, 2012.
[17] B. Bruder, T. Roncalli, *Managing Risk Exposures using the Risk Budgeting Approach*, 2012.
[18] Y. Choueifaty, Y. Coignard,*Toward Maximum Diversification*, The Journal of Portfolio Management, 2008.
[19] J.S. Foresti, M.E. Rush, *Risk-Focused Diversification: Utilising Leverage within Asset Allocation*, California: Wilshire Consulting, 2010.
[20] C. Levell, *Risk Parity: In the Spotlight after 50 Years*, Zagreb: General Research, NEPC, 2010.
[21] H. Lohre, U. Neugebauer, C. Zimmer, *Diversified Risk Parity Strategies for Equity Portfolio Selection*, Journal of Investing, 2012.
[22] S. Maillard, T. Roncalli, J. Teïletche, *The properties of equally weighted risk contribution portfolios*, The Journal of Portfolio Management, 2010.
[23] A. Meucci, *Risk Contributions from Generic User-defined Factors*, The Risk Magazine, 2007.
[24] A. Meucci, *Managing Diversification*, *Risk*, 2009.

Equation (3) is equivalent to solving a nonlinear equation with *n* unknown variables. In this paper, according to Delle Foglie and Pola (2021), we solved the optimisation problem using the MATLAB Optimization Toolbox™, which provides functions for finding parameters that minimise or maximise objectives while satisfying constraints. In particular, the *fmincon* functions of MATLAB provide an SQP-based nonlinear programming solver, finding the minimum of a constrained nonlinear multivariable function of a problem[25] [26]:

$$min_x \, f(x) \; such \; that$$
$$\{c(x) \le 0 \; ceq(x) = 0 \; A \cdot \; x \le b \; Aeq \; \cdot x = beq \; lb \le x \le ub,$$

- *b* and *beq* are vectors, *A* and *Aeq* are matrices, *c*(*x*) and *ceq*(*x*) are functions that return vectors, and *f*(*x*) is a function that returns a scalar. *f*(*x*), *c*(*x*), and *ceq*(*x*) can be nonlinear functions.
- *x*, *lb,* and *ub* can be passed as vectors or matrices.

Optimisation Toolbox™ solvers accept vectors for many arguments (*x0* as initial point, lower bounds *lb* and upper bounds *ub*) and matrices, where the matrix is an array of any size. Here are how solvers handle matrix arguments:

- Internally, solvers convert matrix arguments into vectors before processing. For example, *x0* becomes *x0(:);*
- For output, solvers reshape the solution *x* to the same size as the input *x0;*
- When *x0* is a matrix, solvers pass *x* as a matrix of the same size as *x0* to both the objective function and to any nonlinear constraint function;
- Linear Constraints take *x* in vector form, *x(:)*. In other words, a linear constraint of the form:

$A*x \le b$ *or* $Aeq*x = beq$*,* where it takes *x* as a vector, not a matrix (MathWorks Inc, 2021).

Thus, the appropriate syntax for the Risk Parity optimisation problem solution is[27] [28]:

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[25] H.R. Byrd, J.C. Gilbert, J. Nocedal, *A trust region method based on interior point techniques for nonlinear programming*, Mathematical Programming, 89: 149–85, 2000.

[26] Waltz, A.Richard, J.L. Morales, J. Nocedal, D. Orban, *An interior algorithm for nonlinear optimisation that combines line search and trust region steps,* Mathematical Programming 107: 391–408, 2006.

[27] M.Giuzio, *Genetic algorithm versus classical methods in sparse index tracking,* Decisions in Economics and Finance 40: 243–56, 2017.

[28] N.S.M. Mussafi, I. Zuhaimy, *Optimum Risk-Adjusted Islamic Stock Portfolio Using the Quadratic Programming Model: An Empirical Study in Indonesia*, Journal of Asian Finance, Economics and Business 8: 839–50, 2021.

x = fmincon (fun,x0,A,b,Aeq,beq,lb,ub) (Function 1)

which defines a set of lower and upper bounds on the design variables in *x* so that the solution is always in the range $lb \leq x \leq ub$. The *fmincon* function solves the interior-point algorithm approach to constrained minimisation problems by default. First, Function (1) was designed to solve the optimisation problem in Equation (3). Function (1) represents the MATLAB function computed to solve the optimisation problem shown in Equation (3):

```
fun=@(x)Aeq*(((matrcov(:,:,i)*(x)/(sqrt((x')*matrcov(:,:,i)*x))).*x-
(sqrt((x')*matrcov(:,:,i)*x ))/n_asset)).^2);
```

where *MatrCov* is the variance–covariance matrix, and *n_asset* is the number of the asset classes composing the portfolio. Second, the *fmincon* was applied to Function (1) to solve the optimization problem, writing a string to find the RP portfolio weights.

```
weight_RP(:,i)=fmincon(fun, weight_EW , [] , [] , Aeq , Beq , lb , ub , [] , o).
```

3. The sample selection was designed following the Global Macro strategies fundamentals, building a flexible multi-asset portfolio which considers traditional asset classes such as equities, fixed income instruments, commodities, gold and currencies[29] and REIT, along with alternative asset classes such as Sukuk (Islamic bonds) and Green Bonds. Following Global Macro underpinnings, the asset allocation respects the assumption of Pola (2013)[30] , which assumes a strategic asset allocation based on diversification across macroeconomic scenarios. Notably, since major global indexes are quoted in USD, we also considered the geographical and currency exposure suitable for European-based investors, adding a EUR (Euro)-based bond (and green bond) component and euro-based equities such as the MSCI Europe Price Index. To facilitate the operation of the risk-parity model, we chose not to consider both assets affected by too much and too little volatility, respectively, as commodities and cash. Considering the possibility for investors to use index-tracking instruments, the conventional asset allocation includes 14 indexes with 313 weekly observations (312 weekly returns) from 1 January 2015 to 31 December 2020 (5 years) extracted from Reuters Refinitiv Eikon. Therefore, we created a rolling time window with an in-sample period of 157 weeks (from 2 January 2015 to 29 December 2017) and an out-of-sample period of 156 weeks (from 5 January 2018 to 25 December 2020). According to the aim of this paper, the rolling window allows capturing different market scenarios to test the portfolio during *normal* (2015-2019), turbulent (February-April 2020) and post-stress times (May 2020

[29] See Delle Foglie, A., Pola, G. (2021). *Make the Best from Comparing Conventional and Islamic Asset Classes: A Design of an All-Seasons Combined Portfolio*.
[30]See Pola, G. (2013). *Diversification measures for portfolio selection, New York, NOVA publisher*.

to the end), building a good environment to test the risk-adjusted contributions of asset classes during these times understanding their behaviour. Table 1 summarises each macro-asset class and the corresponding index selected for the asset allocation.

Table 1. Sample composition.

Macro-Asset Class	Index	Code
Equities	MSCI Europe Price Index	MSCIE
	MSCI WORLD Price Index	MSCIW
	MSCI Emerging Market Price Index	MSCIEM
	S&P 500 Index	SP500
Corporate Bonds	IBoxx Eur Liquid High Yield Index	EUROCORP
	IBoxx USD Corporates Index	USCORP
	VanEck Global Fallen Angel High Yield Bond Index	FABOND
Convertible Bonds	Refinitiv Qualified Global Convertible Index	CONVBOND
Inflation-Linked Bond	IBoxx Euro Inflation-Linked Index	EUROIL
Gold	COMEX Gold Composite Commodity Future Continuation	GOLD
REIT	FTSE EPRA NAREIT Global	REIT
Islamic Bonds	Dow Jones Sukuk Index USD	DJS
Green Bonds	IBoxx Global Green Social and Sustainability Index Eur	GSSB
	Solactive Green Bond Index USD	GBSOL

4. Table 2 and Table 3 report the descriptive statistics of the weekly asset returns and the correlation between different portfolio asset classes, respectively. MSCI World and S&P 500 indexes' performances reflect the remarkable performance of the world financial markets in the last five years, recording the highest performance of the other equity indexes. Similarly, last year's monetary stimulus (quantitative easing) and central bank *zero lower bound* monetary policy have also pushed the bond market favouring convertible bonds and sub-investment grade bonds. The convertible bonds mainly demonstrated high resilience during high volatility as in March 2020 and recorded stellar performance in the last five years, giving downside protection and upside participation[31]. Fallen angels' bonds behave similarly to the convertibles. A fallen angel is typically a high yield corporate bond that has been downgraded from investment grade to sub-investment (junk) grade due to financial troubles related to its issuers. In this case, this bond pays higher returns than investment-quality bonds, but they are riskier. Over the past decade, financial markets experienced periods of rising and falling interest rates, extensive and tight credit spreads, and periods of significant

[31] See Schroders, (2021). *Individuals & families, Wealth management at Schroders.*

credit rating upgrades and downgrades. Fallen angels' bonds have historically provided outperformance relative to the broad high yield market through these different market environments due to their unique characteristics. The correlation matrix confirms the trends related to convertible and fallen angels' bonds and government and corporate bonds, which recorded a relative-positive correlation with the equity market. According to Shen and Weisberger (2021)[32] the negative stock-bond correlation recorded in the last ten years seems to be related to low and stable risk-free interest rates and inflation and changes we are experiencing between the end of 2021 and the beginning of 2022 with the inflation and interest rate rising are modifying this trend. In addition, it is also interesting to analyse the role of precious metals such as gold, which has always been considered a safe-haven asset by investors. Due to macroeconomic conditions, gold has recorded performance similar to the equity market, with an average return of 7,55% and a volatility of 14,96%. Finally, for the analysis, we underlined the performance of the Sukuk and Green Bond indexes as alternative assets to the conventional Global Macro portfolio. Both recorded poor performance in risk-adjusted returns according to their low/relative-negative correlation with the equity market.

[32] See Shen, J., Weisberger, N. (2021). *US Stock-Bond Correlation: What Are the Macroeconomic Drivers? PGIM IAS.*

Table 2. Descriptive statistics of asset returns

Notes: This table provides sample moments, Sharpe ratios, and minimum and maximum statistics of all asset classes used in the asset allocation. The evaluation period covered 313 weeks, from 2 January 2015 to 18 December 2020 (312 weekly returns). “Mean” denotes annualised time-series mean of weekly returns, while “Std.Dev.” is the associated annualised standard deviation. “Skew” and “Kurt” represent the third and fourth moments, respectively, of the return distribution. “Sharpe” denotes the annualised Sharpe ratios of the respective asset classes, considering 0.125% as risk-free according to EU zero interest rates policy in recent years. “JB (p-value)” is the p-value of the Jarque–Bera statistic for testing the normality of returns.

	Mean (%)	Std. Dev. (%)	Kurt	Skew	Sharpe	Min	Max	JB (p-Value) (%)	Weekly Returns	Weekly Obs.
MSCIE	2,24	19,35	17,81	-2,02	0,11	-0,23	0,09	0.00	312	313
MSCIW	7,93	16,91	9,94	-1,23	0,46	-0,13	0,10	0.00	312	313
MSCIEM	4,56	18,35	2,91	-0,66	0,24	-0,13	0,07	0.00	312	313
SP500	10,43	17,63	10,65	-1,34	0,58	-0,16	0,11	0.00	312	313
EUROCORP	3,29	6,94	36,75	-3,14	0,46	-0,09	0,05	0.00	312	313
USCORP	5,09	6,27	42,50	-2,72	0,79	-0,08	0,06	0.00	312	313
CONVBOND	9,99	9,80	9,56	-1,20	1,01	-0,10	0,05	0.00	312	313
FABOND	8,62	7,60	27,48	-2,31	1,12	-0,09	0,06	0.00	312	313
EUROIL	2,53	4,85	15,15	-1,82	0,50	-0,05	0,02	0.00	312	313
GOLD	7,55	14,96	2,86	-0,04	0,50	-0,10	0,09	0.00	312	313
REIT	-1,01	19,39	17,18	-1,92	-0,06	-0,21	0,13	0.00	312	313
DJS	1,13	2,98	35,03	-3,98	0,34	-0,04	0,01	0.00	312	313
GSSB	2,46	6,96	9,36	-0,82	0,34	-0,06	0,05	0.00	312	313
GBSOL	3,16	4,38	2,77	-0,69	0,69	-0,03	0,02	0.00	312	313

Table 3. Correlation matrix of asset returns (02/01/2015 to 29/12/2017)

Notes: This table provides the correlation matrix for all asset classes used in asset allocation from 02/01/2015 to 29/12/2017. * and ** indicate values significantly different from 0 at the 1% and 5% level, respectively.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
MSCIE	1,00													
MSCIW	0,89**	1,00												
MSCIEM	0,79**	0,80**	1,00											
S&P500	0,78**	0,97**	0,72**	1,00										
EUROCORP	0,12*	0,18**	0,22**	0,19**	1,00									
USCORP	-0,07	-0,02	0,04	0,03	0,68**	1,00								
CONVBOND	0,14*	0,20**	0,25**	0,21**	0,71**	0,44**	1,00							
FABOND	0,03	0,08	0,14*	0,09	0,92**	0,72**	0,74**	1,00						
EUROIL	0,14*	0,19**	0,15**	0,20**	0,52**	0,49**	0,43**	0,48**	1,00					
GOLD	0,24**	0,19**	0,25**	0,14*	-0,06	-0,07	-0,04	-0,06	-0,01	1,00				
REIT	0,68**	0,73**	0,62**	0,68**	0,20**	-0,03	0,18**	0,08	0,22**	0,26**	1,00			
DJS	0,41**	0,44**	0,46**	0,41**	0,40**	0,34**	0,36**	0,34**	0,41**	0,40**	0,52**	1,00		
GSSB	0,34**	0,30**	0,30**	0,24**	0,20**	0,10	0,20**	0,14*	0,24**	0,51**	0,22**	0,59**	1,00	
GBSOL	-0,07	0,02	-0,01	0,05	0,26**	0,18**	0,14*	0,19**	0,25**	0,03	0,40**	0,44**	-0,07	1,00

5. The first portfolio optimisation starts with the Conventional GM Portfolio, considering an asset allocation based on traditional Global Macro strategies asset classes such as equities, government and corporate bonds, gold, and REIT, for 11 asset classes. According to the previous methodology, a rolling time window with an in-sample period of 157 weeks (from 2 January 2015 to 29 December 2017) and an out-of-sample period of 156 weeks (from 5 January 2018 to 25 December 2020) in order to better capture the crisis and post-crisis scenario. We applied the ERC risk-parity optimization to implement the strategy, starting from an equally weighted (EW) portfolio as an input of the function objective applied in MATLAB (*fmincon* – Function 1). The optimisation algorithm results in portfolio asset allocation based on a risk parity model called RP. To consider the weaknesses and benefits of the ERC optimisation, Table 4 and Figure 1 reports and charts the most relevant statistics, risk-adjusted indicators, and the performance of the Conventional GM Portfolio in the out-of-sample windows (w = 156). In order to better benchmark the performance of the Conventional and Alternative GM Portfolios, we add two of the world's most significant Global Macro strategy-based funds, the Amundi Funds Global Multi-Asset Conservative E2 EUR (C) and the ESG Multi-Asset BlackRock Global Fund.

According to the Global Macro strategy's fundamentals, each asset class in the asset allocation has a specific role in performing and protecting the portfolio against any macroeconomic scenario and market shock as in 2020. The Conventional GM Portfolio based on risk parity asset allocation confirms this trend by recording the best Sharpe Ratio and the best performance (2,03 and 18,07%) with a moderate level of volatility. The maximum drawdown of the portfolio is higher than Benchmark Fund 1 due to the presence of higher volatility assets in the asset allocation. In addition, looking at Table 5, it is interesting to highlight that the RP asset allocation allocated (on average) only 27,48% of the total portfolio amount into higher volatility assets, such as equities, convertible bonds and REITs. The MRCs in Table 6 confirm this trend. Notwithstanding the highest risk-adjusted performance in the RP asset allocation, the MRCs of high volatility assets settle down to 7,49% of the volatility (based on the assumption of the model that the level of the volatility is equal to the Total Risk Contribution – TRC).

Table 4. Main Performance of the Conventional GM Portfolio.

Notes: This table summarises the portfolio out-of-sample performance. "Return" denotes the annualised time-series cumulative return, while "Volatility" shows the associated annualised standard deviation, and "Sharpe Ratio" represents the annualised Sharpe ratio to measure risk-adjusted performance. The "Max Drawdown" (MDD) is the maximum observed loss from a peak to a portfolio trough before a new peak is attained. The "Calmar Ratio" is a risk-adjusted indicator that considers MDD as a risk-adjusted risk indicator. Similarly, "Sortino Ratio" is another risk-adjusted indicator. "Benchmark Fund 1" is Amundi Funds Global Multi-Asset Conservative E2 EUR (C), a global balanced mutual fund and winner of the Morningstar Fund Awards 2021, and "Benchmark Fund 2" is the ESG Multi-Asset BlackRock Global Fund, ESG screened. The cumulative return of the benchmark fund was calculated considering the weekly closing NAV. The benchmark fund was added to facilitate the reading of the results, not for a performance comparison purpose.

	EW	RP	Benchmark Fund 1	Benchmark Fund 2
Return (%)	15,31	18,07	12,87	12,78
Volatility (%)	19,3	13,04	10,45	16,33
Max Drawdown (%)	28,11	18,75	11,06	16,27
Sharpe Ratio	1,36	2,03	0,79	1,49
Sortino Ratio	0,95	1,17	1,67	1,19
Calmar Ratio (%)	20,97	31,94	41,22	29,81

Table 5. Asset marginal weight contribution – Conventional GM Portfolio (out-of-sample period).
Note: This table summarises the asset weight contribution to the total portfolio resulting after the optimisation process.

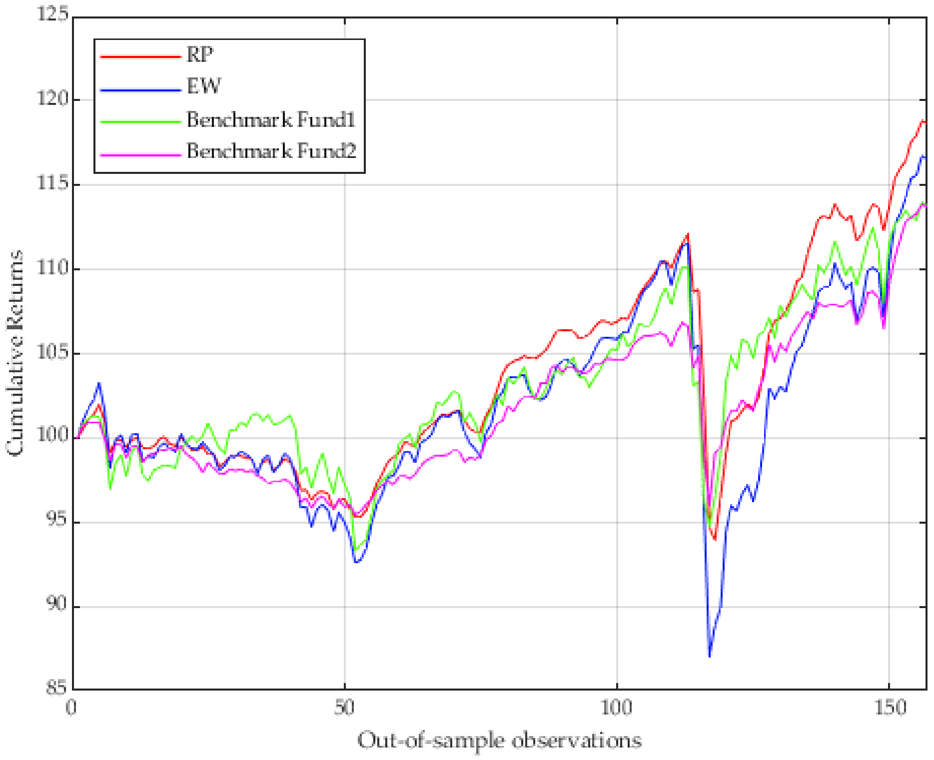
	Mean	Min	Max	Variance
MSCIE	3,71%	2,09%	4,61%	0,002%
MSCIW	3,89%	2,69%	4,58%	0,002%
MSCIEM	3,27%	2,6%	4,75%	0,007%
S&P500	4,02%	2,65%	5,27%	0,003%
CONVBOND	8,14%	6,67%	8,97%	0,003%
REIT	4,45%	2,57%	5,21%	0,001%
High Volatility Assets	27,48%	19,27%	33,39%	0,018%
EUROCORP	15,66%	10,11%	19,47%	0,111%
USCORP	18,32%	16,71%	32,82%	0,029%
EUROIL	17,58%	15,06%	20,28%	0,024%
GOLD	8,27%	5,06%	11,55%	0,027%

Table 6. Assets' marginal risk contributions (MRCs) - Conventional GM Portfolio (out-of-sample period).
Note: This table summarises the assets' MRC to the total portfolio resulting after the optimisation process.

	Mean	Min	Max	Variance
MSCIE	1,39%	1,03%	2,26%	0,0019%
MSCIW	1,34%	0,95%	2,23%	0,0022%
MSCIEM	1,57%	1,26%	2,09%	0,0008%
S&P500	1,32%	0,81%	2,27%	0,0027%
CONVBOND	0,64%	0,46%	1,08%	0,0006%

REIT	1,23%	0,68%	2,28%	0,0037%
High Volatility Assets	7,49%	5,19%	12,21%	0,0118%
EUROCORP	0,4%	0,18%	0,91%	0,0009%
USCORP	0,3%	0,13%	0,55%	0,0002%
FABOND	0,44%	0,21%	0,86%	0,0005%
EUROIL	0,29%	0,19%	0,48%	0,0001%
GOLD	0,62%	0,45%	0,88%	0,0002%

Figure 1. Conventional GM Portfolio Returns (in-sample w = 156; out-of-sample w = 157)
Note: to improve table clarity, returns were normalised on a scale of 100.



6. In this section, we focused on the settlement of the Alternative GM Portfolio. Following the aim of this paper to build and test the performance, hedging and decoupling benefits and risk management, we added to the Conventional GM Portfolio two alternative macro asset classes represented by Sukuk (as Islamic Bonds) and Green Bonds (*DJS, GSSB, GBSOL*). Thus, the Alternative GM Portfolio includes 14 indexes. Again, the observation period consists of 312 weekly returns and the rolling time window relies on 156 weeks in-sample and an out-of-sample of 157 weeks. We applied the Function (1) used to solve the ERC optimisation problem, reporting results and charting the cumulative out-of-sample returns in Table 7 and Figure 2. Unlike the

conventional ones, the Alternative GM Portfolio under the risk parity optimisation recorded an impressive risk-adjusted performance with a Sharpe Ratio equal to 2,55, with an annualised return of 15,24% and a level of volatility of 9,72%. The overall performance of the Alternative GM Portfolio in the ERC approach is the best compared to the Benchmark Funds 1 and 2, except for the maximum drawdown and Calmar Ratio value which is higher than the Benchmark Fund 1. In addition, by increasing the fixed-income component of the asset allocation, the Alternative GM Portfolio recorded better performance than the Conventional. Indeed, looking at Tables 8 and 9, different from previously, the high volatility asset classes' weight contribution and MRCs decrease on average to 19,37% and 7%, respectively. Notably, "alternative" asset classes are well supported by asset diversification since their relevant contribution in terms of risk-adjusted performance. The weight of Sukuk and Green Bonds, respectively, amount to 12,4%, 7,86% and 18,93%, considering their performance during the entire period of observations. During periods of distress, the MRCs of high volatility assets were significant and larger than other asset classes, and generally, the RP model preferred low-volatility assets. For these reasons, in a risk mitigation logic, during high volatility times as during 2020, low volatility asset classes increase the risk-adjusted performance and alternative instruments such as Sukuk or Green Bonds seem to be able to play this role. Finally, looking at the results, Sukuk and green bonds may be integrated into the fixed-income component of the portfolio asset allocation, playing an important role in Global Macro strategies as decorrelating assets.

Table 7. Main Performance of the Alternative GM Portfolio
Note: See notes in Table 4

	EW	RP	Benchmark Fund 1	Benchmark Fund 2
Return (%)	14,51	15,24	12,87	12,78
Volatility (%)	16,12	9,72	10,45	16,33
Max Drawdown (%)	22,96	13,34	11,06	16,27
Sharpe Ratio	1,57	2,55	0,79	1,49
Sortino Ratio	1,04	1,35	1,67	1,19
Calmar Ratio (%)	23,37	38,3	41,22	29,81

Table 8. Asset marginal weight contribution - Alternative GM Portfolio (out-of-sample)
Note: This table summarises the asset weight contribution to the total portfolio resulting after the optimisation process.

	Mean	Min	Max	Variance
MSCIE	2,44%	1,47%	2,89%	0,0005%
MSCIW	2,52%	1,89%	2,98%	0,0003%
MSCIEM	2,07%	1,59%	3,03%	0,0027%

S&P500	2,61%	1,82%	3,57%	0,0007%
CONVBOND	5,32%	4,48%	6,12%	0,0007%
REIT	2,41%	1,67%	3,1%	0,0006%
High Volatility Assets	19,37%	12,92%	21,69%	0,0055%
EUROCORP	9,85%	6,12%	12,97%	0,0529%
USCORP	10,65%	9,65%	22,54%	0,0127%
FABOND	8,06%	6,69%	10,56%	0,0164%
EUROIL	10,49%	9,32%	11,79%	0,0047%
GOLD	4,4%	3,02%	6,38%	0,01%
DJS	12,4%	10,85%	14,4%	0,0062%
GSSB	7,86%	6,81%	9,91%	0,0041%
GBSOL	18,93%	13,23%	23,45%	0,0521%

Table 9. Assets' marginal risk contributions (MRCs) – Alternative GM Portfolio (out-of-sample)
Note: This table summarises the assets' MRC to the total portfolio resulting after the optimisation process.

	Mean	Min	Max	Variance
MSCIE	1,25%	0,85%	2,1%	0,0021%
MSCIW	1,22%	0,86%	2,1%	0,0023%
MSCIEM	1,45%	1,09%	1,94%	0,0008%
S&P500	1,19%	0,71%	2,14%	0,0027%
CONVBOND	0,58%	0,4%	1,07%	0,0007%
REIT	1,31%	0,73%	2,31%	0,0034%
High Volatility Assets	7,00%	5,64%	11,66%	0,012%
EUROCORP	0,38%	0,17%	0,9%	0,0009%
USCORP	0,29%	0,13%	0,53%	0,0002%
FABOND	0,41%	0,19%	0,83%	0,0005%
EUROIL	0,29%	0,19%	0,49%	0,0001%
GOLD	0,68%	0,54%	0,99%	0,0002%
DJS	0,24%	0,14%	0,41%	0,0001%
GSSB	0,39%	0,23%	0,71%	0,0003%
GBSOL	0,16%	0,09%	0,3%	0,0001%

Figure 5. Alternative GM Portfolio returns (in-sample w = 156; out-of-sample w = 157).

Note: To improve table clarity, returns are normalised on a scale of 100.

7. This paper aimed to contribute to the literature on portfolio systemic risk management, examining the hedge and safe-haven properties of alternative asset classes such as Sukuk and green bonds, for the conventional portfolio strategies, during financial market turmoil as in the Covid-19 crisis. In this paper, we mainly build an Alternative Global Macro Portfolio solving a risk-parity optimisation and using a specifically developed MATLAB™ algorithm. We test the risk-adjusted contribution of Sukuk and green bonds as alternatives to the conventional fixed-income instruments.

As previously mentioned, the Covid-19 crisis has increased the need to manage the rise of systemic risk from portfolio management. In this context, findings show that, in a risk mitigation logic, during high volatility times as during 2020, low volatility asset classes increase the risk-adjusted performance, and alternative instruments such as Sukuk or Green Bonds seem to be able to play this role. Finally, looking at the results, Sukuk and green bonds may be integrated into the fixed-income component of the portfolio asset allocation, playing an essential role in Global Macro strategies as decorrelating assets. Our findings align with earlier empirical studies that reported green bonds as a safe-haven investment and a diversifier for multi-asset portfolios and investment opportunities to curb the economic fragility during stress periods, particularly during COVID-19.

Further research in the portfolio risk management industry and systematic risk mitigation could continue studying, separately and together, the behavior and the performance of this kind of strategy or others adopted mainly by fund managers, also applying more quantitative methods. However, it is necessary to keep in mind that it is impossible to completely delete the effect of the systematic risk in the portfolio risk management, so it is important to find new methods to mitigate and manage it.

Sébastien Laurent, Christelle Lecourt and Rosnel Sessinou

ARE FRENCH SMALL- AND MID-CAP STOCKS AN ALTERNATIVE PROFITABLE ASSET CLASS IN PERIODS OF FINANCIAL CRISIS?*†

ABSTRACT

L'obiettivo del lavoro è quello di verificare se le azioni cd. Small- o mid-cap. possano essere considerate un asset class in grado di migliorare le caratteristiche del portafoglio di investimento in termini di media-varianza. Analizzando i titoli francesi quotati sul mercato Euronext da gennaio 2000 a dicembre 2018, si prende in esame il punto di vista di un investitore che investe large-cap. domestiche e che possa essere disposto ad inserire nel proprio portafoglio small- mid-cap. Esaminiamo inoltre il punto di vista di un investitore che ha un portafoglio diversificato a livello geografico utilizzando indici internazionali su azioni large-cap. Infine, si valuta se la performance cd. size-based del portafoglio varia nel tempo. I risultati mostrano che è possibile trarre vantaggio dall'aggiunta di titoli small- mid-cap. nei portafogli di investimento proprio perché la performance del portafoglio basata sulle dimensioni varia nel tempo. In particolare, si dimostra che i titoli a piccola e media capitalizzazione si comportano in modo diverso rispetto a quelli alle large-cap durante e dopo le crisi finanziarie, il che significa che possono essere considerati come una classe di attività redditizia alternativa nella gestione del portafoglio. Questo risultato è robusto alle

In this paper, we investigate whether small- or mid-cap stocks can be considered as an alternative asset class that allows for the enhancement of the mean-variance characteristics of an investor's portfolio. Using all the French stocks listed on the Euronext Stock Market from January 2000 to December 2018, we first examine this issue from the perspective of an investor that invests in familiar asset classes such as domestic large-cap stocks and is willing to add small- and/or mid-cap domestic stocks to his or her portfolio. We also examine this issue from the perspective of a French investor who has internationally diversified his portfolio using only international large- cap indices. Finally, we attempt to measure whether the size-based performance of a portfolio varies over time. We show that investors may benefit from adding micro- or small-cap stocks to their portfolios due to the fact that size-based portfolio performance varies over time. In particular, we find that small and mid-cap stocks behave differently to large-cap stocks during and after the financial crisis, meaning that they can be considered as an alternative profitable asset class in portfolio management. This result is robust to different methodologies used to classify size-based

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diverse metodologie utilizzate per classificare i portafogli basati sulle dimensioni e ai diversi set di asset di riferimento.
Ad eccezione dei titoli a grande capitalizzazione all'inizio della crisi finanziaria, l'ipotesi dello spanning non può essere respinta per i portafogli a piccola, media o grande capitalizzazione nel periodo 2007-2012, ma l'ipotesi è respinta per tutti i portafogli a piccola capitalizzazione nel periodo 2012-2018. I risultati evidenziano che i titoli francesi small-cap si comportano in modo diverso rispetto a quelli a media e grande capitalizzazione, e differiscono anche quando il loro comportamento viene confrontato con quello di altre classi di attività internazionali.

portfolios as well as to different sets of benchmark assets. Except in the case of large-cap stocks at the beginning of the financial crisis, the spanning hypothesis cannot be rejected for small-, mid- or large-cap portfolios during the period spanning from 2007-2012, but the hypothesis is rejected for all small-cap portfolios during the period spanning from 2012-2018. Our results show that French small-cap stocks behave differently than mid- and large-cap stocks behave, and they also differ when their behavior is compared to that of other international asset classes.

KEYWORDS

Small- and mid-cap stocks; diversificazione di portfolio; asset allocation

Small- and mid-cap stocks; portfolio diversification; asset allocation

SUMMARY: 1. Introduction – 2. Related literature – 3. Description of the data and descriptive statistics – 4. Methodology and results – 5. Conclusions

1. The benefits of portfolio diversification are an important issue for both individual and institutional investors. Since the works of Grubel (1968)[1] and Levy and Sarnat (1970)[2] were published, numerous studies have documented the additional benefits of international portfolio diversification that arise from the low correlation among international securities compared to domestic securities. With the integration of the international financial markets, however, stock market correlations have increased, limiting the potential benefits derived from international diversification[3]. Despite the increasing correlation among international stock market securities, portfolio diversification favors large-cap stocks. This large-cap bias is partially explained by investors' preference for holding stock securities in large, well-known and visible multinational companies. Another factor that strengthens this large-cap bias is that investors prefer to invest in asset classes that they are more familiar with, such as those of national stock market indices dominated by large-cap stocks. Huberman (2001)[4] explains this phenomenon by the fact that familiarity breeds investment.

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[3] See, among others, F. Longin, B. Solnik, *Is the correlation in international equity returns constant: 1960-1990?*, Journal of International Money and Finance 14, 1995, p. 3 ss.; W. Goetzmann, L. Li, K. Rouwenhorst, *Long-term global market correlations*, Journal of Business 78, 2005, p. 1 ss.
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Despite their recognized economic and social importance, listed small- and medium-sized companies do not seem to enjoy the same appeal as do large-cap companies. However, according to standard portfolio theory, if small-cap stock returns are not perfectly correlated with large-cap stock returns, the addition of small-cap stocks may increase the mean-variance of an existing portfolio.

The concept of considering small-cap stocks as an effective asset class for portfolio diversification is interesting for several reasons. First, a large number of studies show that there is a difference between the return behaviors of small-cap stocks and those of large-cap stocks[5] [6] and that the correlations between small portfolios and large portfolios are less than one[7] [8] [9] [10]. Second, related to the first point, the return-generating mechanisms for large- and small-mid-cap stocks are different [11] [12] [13]. In particular, the returns of large caps are mostly driven by common global factors, while those of small-cap stocks are driven by local, idiosyncratic factors. This is because large-cap stocks come from multinational companies that are more exposed to common global shocks than locally oriented firms are[14]. In contrast, small- and mid-cap stocks are more locally oriented with limited international exposure[15]. Third, in reference to the seminal studies of Banz (1981)[16] and Reinganum (1992)[17], some papers have reported that small-cap stocks outperformed large-cap stocks during long-term holding periods, which we call the "small-cap anomaly" in reference to the efficient markets

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[5] R. Banz, *The relationship between return and market value of common stock*, Journal of Financial Economics 9, 1981, p. 3 ss.

[6] K.C. Chan, N. Chen, *Structural and return characteristics of small and large firms*, Journal of Finance 46 (4), 1991, p. 1467 ss.

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[9] C. Eun, W. Huang, S. Lai, *International diversification*, Journal of Portfolio Management 28 (3), 2002, p. 82 ss.

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[11] R. Banz, *The relationship between return and market value of common stock*, cit., p. 3 ss.

[12] K.C. Chan, N. Chen, *Structural and return characteristics of small and large firms*, cit., p. 1467 ss.

[13] L. Switzer, *The behavior of small-cap vs. large-cap stocks in recessions and recoveries: empirical evidence for the United States and Canada*, cit., p. 332 ss.

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[16] R. Banz, *The relationship between return and market value of common stock*, cit., p. 3 ss.

[17] M. Reinganum, *Misspecification of capital asset pricing: empirical anomalies based on earnings*, Journal of Financial Economicst 9 (1), 1981, p. 19 ss.

paradigm[18] [19], though this relative performance between small-and large-cap stocks does not seem to be consistent over time and among different countries. Fourth, small-cap stock indices have been developed around the world in recent years; this reduces the transaction costs incurred by investors interested in diversifying their portfolios using small caps as a new asset class. Finally, the benefits of size diversification have received little attention, especially in the context of non-US markets. Even if there are studies that have investigated the benefits of international diversification[20] [21], to our knowledge, there is no paper dedicated to the analysis of small- and mid-cap stocks in the context of the French stock market.

The question that we investigate in this paper is whether small- or mid-cap stocks can be considered as an alternative asset class that allows us to enhance the mean-variance characteristics of an investor's portfolio. Using all the French stocks listed on the Euronext Stock Market from January 2000 to December 2018, we first examine this issue from the perspective of an investor investing in familiar asset classes such as those of domestic large- cap stocks and willing to add small- and/or mid-cap domestic stocks to his/her portfolio. We also examine this issue from the perspective of a French investor who has internationally diversified his portfolio using only international large-cap indices. Finally, we attempt to measure whether the performance of a portfolio varies over time based on its size.

To investigate the hypothesis regarding the classification of size-based portfolios as autonomous asset classes, we apply the mean-variance spanning test of Huberman and Kandel (1987)[22] to size-sorted portfolios classified using different approaches. The results of our analysis show that investors may benefit from adding micro- or small-cap stocks to their portfolios. This result is robust to different methodologies used to classify size-based portfolios as well as to different sets of benchmark assets. When we employ international stock market indices as benchmark assets, we find that the inclusion of small- and mid-cap French stocks in a portfolio improves its Sharpe ratio and decreases its variance, whereas the inclusion of only large-cap French stocks decreases the variance of a portfolio without improving its Sharpe ratio. Third, the application of the rolling window methodology to the mean-variance spanning test allows us to highlight the large variability that occurs over time in the test results. Except in the case of large-cap stocks at the beginning of the financial crisis, the spanning hypothesis cannot be rejected for small-, mid- or large-cap portfolios during the period spanning from 2007-2012, but the hypothesis is rejected for all small-cap

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[18] J. Siegel, *Stocks for the long run*, New York, Mc Graw Hill, 1998.
[19] E. Dimson, P. Marsh, *Murphy's law and market anomalies*, Journal of Portfolio Management 25 (2), 1999, p. 53 ss.
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portfolios during the period spanning from 2012-2018. Our results show that French small-cap stocks behave differently than mid- and large-cap stocks behave, especially during and after periods of the financial crisis, and they also differ when their behavior is compared to that of other international asset classes. Based on our results, we can conclude that there are benefits related to investing in French small caps from the perspective of portfolio efficiency.

The paper is organized as follows. Section 2 provides a review of the literature related to small- and mid-cap stocks. Section 3 describes the data that are analyzed, while Section 4 explains the methodology used in this paper and discusses the empirical results. The conclusions of this paper are presented in Section 5.

2. The negative association between stock returns and firm size in terms of market capitalization was first documented in the early 1980s[23] [24] [25].

Banz (1981)[26] reports that small-cap stocks have a tendency to earn higher returns over long investment horizons than do large-cap stocks even after adjusting these returns for the market risk. This size effect is considered an anomaly according to traditional asset pricing theory.

A number of potential explanations for this size effect have been proposed in the literature[27]. The first explanation, proposed by Banz (1981)[28], is that small stocks have a higher information risk that can be attributed to the lower quality of the information disclosures provided by small-cap firms. Consequently, small-cap stocks should generate higher returns to compensate for this risk. Another commonly proposed explanation is the fact that small- cap firms have a higher risk of financial distress; therefore, they may face costs of bankruptcy and other types of financial distress[29] [30] [31] [32]. Investors may ask small firms for higher returns to compensate for this expectation of higher distress risk. Another reason proposed by Stoll and Whaley (1983)[33] is that the abnormal risk-adjusted returns of small-cap stocks may be explained by their higher transaction costs, but these results are affected by the length of the investment horizon;

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[23] R. Banz, *The relationship between return and market value of common stock*, cit., p. 3 ss.

[24] M. Reinganum, *Misspecification of capital asset pricing: empirical anomalies based on earnings*, cit., p. 19 ss.

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[26] R. Banz, *The relationship between return and market value of common stock*, cit., p. 3 ss.

[27] See the recent survey by Astakhov et al. (2019) on the link between firm size and stock returns.

[28] R. Banz, *The relationship between return and market value of common stock*, cit., p. 3 ss.

[29] K.C. Chan, N. Chen, *Structural and return characteristics of small and large firms*, cit., p. 1467 ss.

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[31] N. Chen, F. Zhang, *Risk and return of value stocks*, Journal of Business 71, (4), 1998, p. 501 ss.

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for example, small-cap stocks generate lower returns than do large- cap stocks if they are bought and subsequently held for two months or less. The returns of small-cap stocks become positive when the investment horizon increases. Finally, it is known that small-cap stocks have greater illiquidity than do large-cap stocks[34] [35] [36]. Liquidity is generally defined as the ability to trade large quantities of stock quickly, at a low cost, and with little impact on its price, which implies four dimensions: trading quantity, trading speed, trading cost, and price impact[37]. Trading costs are likely higher for small-cap stocks than they are for large-cap stocks due to both the greater impact of a large-volume transaction on the stock price and the wider relative bid-ask spreads. Consequently, investors will charge an illiquidity premium when investing in small-cap stocks while they do not charge this premium in the case of large-cap stocks; therefore, the higher return of a small-cap stock reflects compensation for its lower liquidity. Another explanation proposed for explaining the difference between small- and large-cap returns is related to the dividend performance of small-cap stocks[38] [39]. Dimson and Marsh (1999)[40] find that this size effect is mainly due to differences between the dividend growth of small- and large-cap stocks. Finally, this size effect could result in differences between the sector-related performance of small- and large-cap stocks. In particular, Dimson and Marsh (1999)[41] find that a considerable portion of the size effect is explained by differences among sector weightings.

Even though theoretical explanations have been proposed that establishes firm size as a pricing factor in all major asset pricing models (see the three-factor model[42], the four-factor model[43] and the five- factor model[44] used to estimate expected stock returns), empirical research on the size effect revealed several puzzling characteristics that fueled skepticism regarding this issue. First, these high returns of small caps may

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[36] A. Astakhov, T. Havranek, J. Novak, *Firm size and stock returns: a quantitative survey*, Journal of Economic Survey 33 (5), 2019, p. 1463 ss.
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[38] E. Dimson, P. Marsh, *Murphy's law and market anomalies*, cit., p. 53 ss.
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[40] E. Dimson, P. Marsh, *Murphy's law and market anomalies*, cit., p. 53 ss.
[41] E. Dimson, P. Marsh, *Murphy's law and market anomalies*, cit., p. 53 ss.
[42] E.F. Fama, K.R. French, *Multifactor explanations of asset pricing anomalies*, cit., p. 55 ss.
[43] M.M. Carhart, *On persistence in mutual fund performance*, Journal of Finance 52 (1), 1997, p. 57 ss.
[44] E.F. Fama, K.R. French, *Multifactor explanations of asset pricing anomalies*, cit., p. 55 ss.

be country dependent[45] and/or may vary across regions[46] [47]. Second, many studies highlight the time-varying nature of firm size. According to Stoll and Whaley (1983)[48], whether an investor is able earn abnormal returns net of transaction costs from small-cap stocks is "contingent upon the length of investment horizon". More precisely, small-cap stocks earn higher returns than do large-cap stocks if they are bought and subsequently held for at least two months or more. Similarly, Reinganum (1992)[49] finds that this size premium exhibits predictable patterns and tends to reverse over the course of long time horizons. Some papers explain this time-varying nature by the cyclical behavior of the size effect. Kim and Burnie (2002)[50] observe that the size premium, i.e., the difference between the returns of a portfolio containing small-cap stocks and those of a portfolio containing large-cap stocks, is higher during phases of economic expansion but lower during those of economic contraction. This under-performance of small caps can be explained by the relatively lower productivity and higher financial leverage exhibited during economic down- turns[51] [52]. In the same way, Switzer (2010)[53] finds that small-cap firms outperform large-cap firms during the year subsequent to an economic trough but tend to lag the year prior to a business cycle peak. This cyclical behavior of the size effect contrasts with the notion of systematic risk, which expects low returns on risky assets during economic downturns[54]. Related to this, some papers find that the size premium is concentrated during the month of January, which is also known as the riskiest month of the year[55] [56]. Finally, another puzzling characteristic of small-cap stocks is that the size effect mostly stems from the smallest stocks[57] [58] [59]. For

[45] L. Switzer, H. Fan, *Spanning tests for replicable small-cap indexes as separate asset classes: Evidence from G-7countries*, Journal of Portfolio Management 33 (4), 2007, p. 102 ss.
[46] K. Hou, G.A. Karolyi, B. Kho, *What factors drive global stock returns?*, Review of Financial Studies 24 (8), 2011, p. 2527 ss.
[47] N. Cakici, Y. Tang, A. Yan, *Do the size, value, and momentum factors drive stock returns in emerging markets?*, Journal of International Money and Finance 69, 2016, p. 179 ss.
[48] H. Stoll, R. Whaley, *Transaction costs and the small firm effect*, cit., p. 57 ss.
[49] M. Reinganum, *A revival of the small-firm effect*, Journal of Portfolio Management 18 (3), 1992, p. 55 ss.
[50] M.K. Kim, D.A. Burnie, *The firm size effect and the economic cycle,* Journal of Financial Research 25 (1), 2002, p. 111 ss.
[51] K.C. Chan, N. Chen, *Structural and return characteristics of small and large firms*, cit., p. 1467 ss.
[52] M.K. Kim, D.A. Burnie, *The firm size effect and the economic cycle,* cit., p. 111 ss.
[53] L. Switzer, *The behavior of small-cap vs. large-cap stocks in recessions and recoveries: empirical evidence for the United States and Canada*, cit., p. 332 ss.
[54] A. Astakhov, T. Havranek, J. Novak, *Firm size and stock returns: a quantitative survey*, cit., p. 1463 ss.
[55] D.B. Keim, *Size-related anomalies and stock return seasonality,* cit., p. 13 ss.
[56] J.Hur, G. Pettengill, V. Singh, *Market states and the risk-based explanation of the size premium*, Journal of Empirical Finance 28, 2014, p. 139 ss.
[57] R. Banz, *The relationship between return and market value of common stock*, cit., p. 3 ss.
[58]J. Berk, *An empirical reexamination of the relation between firm size and return*, Working Paper, University of Washington, 1996.
[59] P.J. Knez, M.J. Ready, *On the robustness of size and book-to-market in cross- sectional regressions*, Journal of Finance 52 (4), 1997, p. 1355 ss.

example, Knez and Ready (1997)[60] find that the size effect is driven by the extreme 1% of the observations examined, and when these extreme observations are trimmed each month, the size premium completely disappears.

3. We extract data on all (i.e., 855) the French stocks listed on the Euronext Paris exchange between January 2000 and December 2018 from Datastream. Our dataset includes monthly stock prices and returns, the number of common shares outstanding and the market capitalisation of each stock. We exclude noncommon stocks, REITs and closed-end funds from our sample. We consolidate both the active and the inactive stock files to avoid survivorship bias in our data, and we only select stocks for which data are available for all the variables analyzed. To filter out the recording errors embedded in Datastream, we consider monthly holding period returns greater than 400% to be missing values[61].

We extend our analysis to assess the potential benefits of diversification by utilizing a portfolio consisting of international large-cap stocks (Australia, Canada, Germany, Hong Kong, Italy, Japan, the Netherlands, the U.K., and the U.S) and by introducing internationally diversified small- and mid-cap French stocks to this portfolio. The large-cap portfolios of the aforementioned countries are proxied by the MSCI index obtained from Datastream.

We construct size-based portfolios based on two different methodologies: a threshold approach and a ranking based on quartiles, quantiles and deciles.

The threshold approach, which is mostly used by market professionals of the Euronext Paris exchange, divides listed French stocks into three sub-funds according to their market capitalisation: the first sub-fund includes stocks with a market capitalisation of more than 1 billion euros (“large-caps”); the second includes stocks with a market capitalisation between 150 million euros and 1 billion euros (“mid-caps”); and the last sub-fund includes stocks with a market capitalisation of less than 150 million euros (“small-caps”). The latter class is divided into micro-caps (stocks with a market capitalisation of less than 50 million euros) and small-caps (stocks with a market capitalisation of more than 50 million euros)[62].

Quartile-, quantile- and decile-based portfolios are constructed by first sorting all the stocks in ascending order of their market capitalisation at the end of each calendar year (31 *st* of December on year *t*) and by assigning each stock to the proper percentile based on this ranking. Quartile-, quantile- and decile-based portfolios are then formed for the calendar year $t + 1$, and these portfolios are rebalanced each year. The market

[60] P.J. Knez, M.J. Ready, *On the robustness of size and book-to-market in cross- sectional regressions*, cit., p. 1355 ss.
[61] Ince and Porter (2006) shows that this threshold is somewhat arbitrary and can be higher or lower depending on markets.
[62] As our monetary figures are in US dollars, these thresholds have been converted into US dollars.

capitalization of each stock is used to determine its weight in a portfolio[63]. We then compute the monthly value- weighted returns for each portfolio in terms of US dollars. Whereas quartile and quantile rankings are frequently used in empirical studies, this categorization of portfolios by decile allows us to refine our results and to observe the effect of portfolios made up of extreme values in terms of market capitalization.

Table 1 reports the summary statistics of the portfolios after their categorization by size using the different approaches described above. Several insights emerge from this table. First, returns increase with a decrease in market capitalisation regardless of the approach used to form the portfolios, suggesting the existence of a positive risk premium as found in the literature. When the portfolios are divided into deciles (Panel D), the negative relationship between rate of return and market capitalisation is found to be non-linear, particularly when we consider the extreme observations. This is the case for the first decile representing the "nano" firms (firms with less than 4 million euros of average market capitalisation).

The smallest-sized category of portfolios have a higher volatility than does the largest-sized category, meaning that micro- and small-caps are riskier than others.

One explanation for this phenomenon is that small- and even micro-cap firms have a higher risk of financial distress; therefore, they may face costs of bankruptcy and other types of financial distress[64] [65] [66] [67].

Table 1: Summary statistics for the size-based portfolios

This table reports the following descriptive statistics for size-based portfolios of French stocks listed on the Euronext Paris exchange: the average number of stocks (Nb Stocks), the annualized mean returns (Returns), the average market capitalisation in USD million (Mcap), the annualized standard deviation (SD), the Sharpe ratio (SHP) and the correlation with large-cap MSCI country indexes for Australia, Canada, Germany, Hong Kong, Italy, Japan, the Netherlands, the U.K., and the U.S. The sample was drawn from the period spanning from January 2000 to December 2018. The risk-free interest rate is proxied by the Euribor one month rate averaged over the sample period, which is 0.083% per month. Portfolios are formed using the threshold approach (Panel A), size quartiles (Panel B), size quantiles (Panel C) and size deciles (Panel D). In the threshold approach (Panel A), French stocks with market capitalisation less than or equal to 50 million euros are defined as "Micro-cap", stocks with market capitalisation greater than 50 million euros but less than or equal to 150 million euros are defined as "Small-cap", stocks with market capitalisation greater than 150 million euros but less than 1 billion euros are defined as "Mid-cap" and stocks with market capitalisation greater than or equal to 1 billion euros are defined as "Large-cap" (these monetary figures in euros have been converted to USD). Quartile-, quantile- and decile-based portfolios are constructed by first sorting all the stocks in ascending order of their market capitalisation at the end of each calendar year (31^{st} of December of year t) and by assigning each stock to the proper percentile based on this ranking.Portfolios are then formed based on Quartile, quantile and decile rankings for the calendar year $t + 1$, and the portfolio is rebalanced each year. To accomplish this, we use the market capitalisation of each stock to determine its weight in a portfolio. We then compute the monthly

[63] Market capitalisation is computed by multiplying the total number of a company's common outstanding shares by the current market price of one of its shares.
[64] K.C. Chan, N. Chen, *Structural and return characteristics of small and large firms*, cit., p. 1467 ss.
[65] E.F. Fama, K.R. French, *Multifactor explanations of asset pricing anomalies*, cit., p. 55 ss.
[66] N. Chen, F. Zhang, *Risk and return of value stocks*, cit., p. 501 ss.
[67] M. Vassalou, Y. Xing, *Default risk in equity returns*, cit., p. 831 ss.

value of weighted returns for each portfolio in terms of US Dollars. Portfolios are ranked from the lowest to the highest in terms of market capitalization.

	Nb stocks	Returns	Mcap	SD	SHP	CORR(MSCI)
Panel A: Threshold Approach						
Micro-cap	230	10.9%	18	19.1%	0.52	0.62
Small-cap	117	10.0%	100.51	20.1%	0.45	0.69
Mid-cap	142	9.9%	509.56	19.3%	0.46	0.74
Large-cap	110	7.0%	17861	19.7%	0.30	0.80
Panel B: Quartile Portfolios						
1	150	11.8%	11.234	23.4%	0.46	0.51
2	149	11.2%	66.894	19.1%	0.54	0.69
3	149	9.8%	357.18	19.5%	0.45	0.73
4	150	7.1%	14299	19.6%	0.31	0.80
Panel C: Quantile Portfolios						
1	120	11.0%	8.4735	25.2%	0.40	0.46
2	120	10.7%	39.678	20.1%	0.48	0.61
3	120	9.9%	147.44	19.6%	0.46	0.71
4	119	9.7%	616.42	20.0%	0.43	0.74
5	120	7.1%	17602	19.7%	0.31	0.80
Panel D: Decile Portfolios						
1	60	4.8%	4.0307	29.3%	0.13	0.38
2	60	14.8%	12.957	27.1%	0.51	0.41
3	60	14.3%	26.912	24.5%	0.54	0.53
4	59	8.8%	52.589	19.3%	0.41	0.60
5	60	12.1%	99.01	20.2%	0.55	0.69
6	60	8.8%	195.21	19.9%	0.39	0.69
7	60	11.3%	372.55	20.4%	0.50	0.72
8	60	9.0%	858.05	20.2%	0.39	0.73
9	60	10.4%	2934.1	21.0%	0.45	0.77
10	60	6.8%	32139	19.7%	0.30	0.80

Third, the Sharpe performance measure indicates that the smallest-sized category of portfolios outperforms the largest-sized category, with the exception of the smallest class of portfolios (the first category in the quartile, quantile and decile ranking). Finally, consistent with Eun et al. (2008)[68], there is a positive relationship between the size category of a portfolio and its correlation with the other MSCI country indices, suggesting that small- and mid-cap stocks might facilitate improved international portfolio diversification.

Table 2 shows the correlation structures of the size-based portfolio returns. As expected, the lowest correlation coefficients are found between the small- and large-cap portfolio returns regardless of the size-ranking methodology used: the correlation between the smallest-sized portfolio and the largest-sized portfolio is 0.82 using the threshold approach, 0.58 using quartile ranking and 0.51 using the quantile method.

Table 2: Returns correlation matrix

This table presents the correlation matrix of the size-based portfolio returns. The portfolios classified using the threshold portfolio approach are denoted as S, M and L for small-cap, mid-cap and large-cap,

[68] C. Eun, W. Huang, S. Lai, *International diversification with large and small-cap stocks*, cit., p. 489 ss.

respectively, whereas the portfolios classified using quartile and quantile approaches are denoted as 4*Qx* with *x* = 1, ..., 4 and 5*Qy* with *y* = 1, ..., 5, respectively.

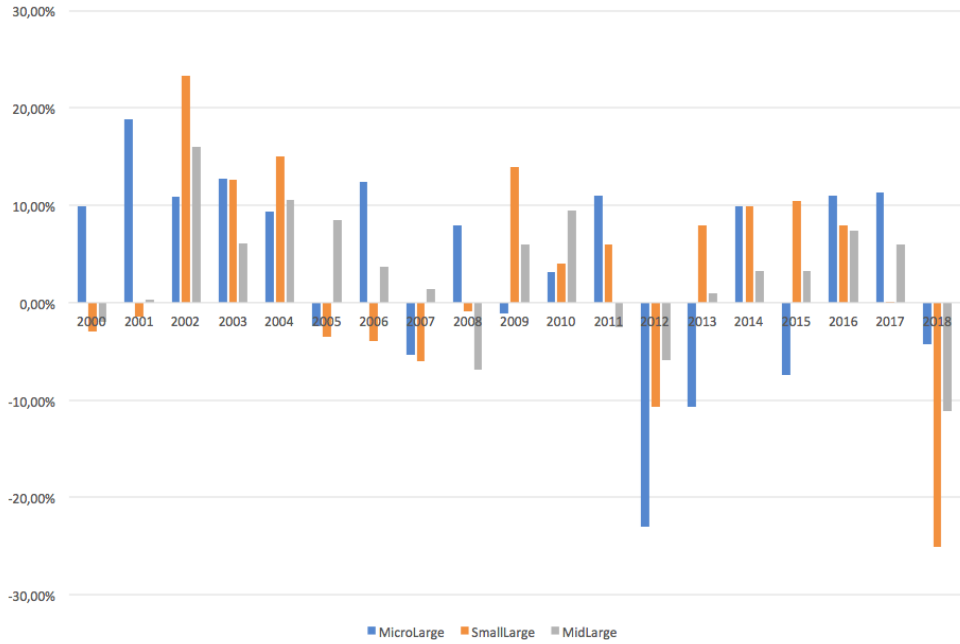
	S	M	L	4Q1	4Q2	4Q3	4Q4	5Q1	5Q2	5Q3	5Q4	5Q5
S	1.00	0.94	0.82	0.79	0.97	0.95	0.82	0.70	0.92	0.97	0.94	0.82
M		1.00	0.89	0.71	0.93	0.98	0.89	0.63	0.83	0.96	0.98	0.89
L			1.00	0.58	0.81	0.87	1.00	0.51	0.72	0.83	0.88	1.00
4Q1				1.00	0.72	0.72	0.58	0.89	0.75	0.73	0.71	0.58
4Q2					1.00	0.93	0.82	0.62	0.93	0.95	0.92	0.81
4Q3						1.00	0.87	0.64	0.85	0.97	0.98	0.87
4Q4							1.00	0.52	0.73	0.84	0.88	1.00
5Q1								1.00	0.57	0.64	0.62	0.51
5Q2									1.00	0.84	0.83	0.73
5Q3										1.00	0.96	0.84
5Q4											1.00	0.88
5Q5												1.00

These results suggest that small caps enhance portfolio diversification[69]. However, the correlation levels among different size- ranking methodologies are relatively different, which justifies a comparison of the different methods used to form portfolios.

To capture the time-varying nature of the size premium described in the literature[70] [71] [72] [73], we compute the size premium for each year during the period spanning from 2000-2018. Figure 1 shows the size premiums for the portfolios categorized based on the threshold approach. *"MicroLarge"* denotes the difference in returns between the portfolios containing micro- cap stocks and those containing large-cap stocks, *"SmallLarge"* denotes the difference in returns between the portfolios containing small-cap stocks and those containing large-cap stocks and *"MidLarge"* denotes the difference in returns between the portfolios containing mid-cap stocks and those containing large-cap stocks.

[69] We do not present the correlation matrix of the portfolios classified using deciles to save space.
[70] H. Stoll, R. Whaley, *Transaction costs and the small firm effect*, cit., p. 57 ss.
[71] K.C. Chan, N. Chen, *Structural and return characteristics of small and large firms*, cit., p. 1467 ss.
[72] M.K. Kim, D.A. Burnie, *The firm size effect and the economic cycle*, cit., p. 111 ss.
[73] L. Switzer, *The behavior of small-cap vs. large-cap stocks in recessions and recoveries: empirical evidence for the United States and Canada*, cit., p. 332 ss.

Figure 1: Size premium - 2000-2018



Three comments are in order. First, we see a large amount of variability among the size premiums regardless of the type of portfolio examined (micro-, small- and mid-cap). The smallest cap portfolios, therefore, are more likely to generate both higher and lower returns than those of the large-cap portfolios over time. Second, the size premium is concentrated in the smallest stocks (namely, micro- stocks), as noted in the empirical literature[74,75]. Third, the size premium was positive during the financial crisis and largely negative at the end of the financial crisis in 2012. This result is consistent with certain empirical studies[76] [77] that find that the size premium is positive when there is a general decreasing trend among stock prices (namely, in a down market), whereas this premium is close to zero or negative when stock prices are experiencing a general upward trend (namely, in an up market).

[74] R. Banz, *The relationship between return and market value of common stock*, cit., p. 3 ss.
[75] P.J. Knez, M.J. Ready, *On the robustness of size and book-to-market in cross- sectional regressions*, cit., p. 1355 ss.
[76] J.Hur, G. Pettengill, V. Singh, *Market states and the risk-based explanation of the size premium*, cit., p. 139 ss.
[77] L. Switzer, *The behavior of small-cap vs. large-cap stocks in recessions and recoveries: empirical evidence for the United States and Canada*, cit., p. 332 ss.

4. The mean-variance spanning test tests whether an asset contributes to the efficient frontier of a mean-variance investor. Assume that Q assets are available and denote $y_{q,t}$ as the return of the q-th asset, $q = 1, \ldots, Q$. Following Huberman and Kandel (1987)[78], hereafter HK, we test whether asset q contributes to the efficient frontier by employing the following linear regression model:

$$y_{q,t} = \alpha_q + \sum_{q \neq q', q'=1}^{Q} \beta_{q,q'} y_{q',t} + \epsilon_{q,t}, q = 1, \ldots, Q, \tag{1}$$

where $E(\epsilon_{q,t}) = 0$, $E(\epsilon_{q,t}^2) = \sigma_q^2$, $E(X_{q,t}\epsilon_{q,t}) = 0_{Q-1}$ and $X_{q,t} = \{y_{q',t}\}_{q' \neq q}$.

Let $\delta_q = \sum_{q \neq q', q'=1}^{Q} \beta_{q,q'} - 1$.

The null of the mean-variance spanning test is equivalent to the joint hypothesis that $\alpha_q = 0$ and $\delta_q = 0$. The test statistic used is Fisher's test statistic with 2 and $T - Q$ degrees of freedom.

Denote $Yt = (y_{1,t}, \ldots, y_{Q,t})1$ as the vector of the returns of the Q assets. Define the expected returns of the Q assets as $\mu = E(Y_t)$, the covariance matrix of the returns as $V = V(Y_t)$ and let $\Theta = V^{-1}$ be the precision matrix. To understand the two conditions $\alpha_q = 0$ and $\delta_q = 0$, we consider two portfolios on the minimum-variance frontier of the Q assets with weights denoted as:

$$\omega_1 = \frac{\Theta\mu}{1'_Q\Theta\mu}, \tag{2}$$

$$\omega_2 = \frac{\Theta 1_Q}{1'_Q\Theta 1_Q}, \tag{3}$$

where 1_Q is a vector of 1 of dimension Q. The first portfolio is a tangency portfolio in which the tangent line starts from the origin[79], and the second portfolio is a global minimum-variance portfolio[80]. The following well-known result (Lemma 1) shows that the empirical counterparts of Θ and μ are sufficient statistics for the α_q and δ_q of all q. Consequently, we may propose a link between α_q (δ_q) and ω_1 (ω_2).

[78] G. Huberman, S. Kandel, *mean-variance spanning*, cit., p. 873 ss.
[79] R. C. Merton, *On estimating the expected return on the market: An exploratory investigation*, Journal of Financial Economics 8, 1980, p. 323 ss.
[80] G.W. Schwert, *Anomalies and market efficiency*, in G.M. Constantinides, M. Harris and R. Stulz (Eds) *Handbook of Economics and Finance* 18, 2003, p. 939 ss.

Lemma 1. *Let* $G = Diag(\frac{1}{\Theta_{1,1}}, \ldots, \frac{1}{\Theta_{Q,Q}})$ *be a diagonal matrix of the same dimension as* Θ. *One has:*

1. $\sigma_q^2 = \frac{1}{\Theta_{q,q}}$, $q = 1, \ldots, Q$;

2. $\beta_{q,q'} = -(G\Theta)_{q,q'}$, $\forall\ q, q' = 1, \ldots, Q$, $q \neq q'$;

3. $\alpha = (\alpha_1, \ldots, \alpha_Q)' = G\Theta\mu$.

Proof. See Peng et al. (2005)'s Lemma 1. □

From Lemma 1, we deduce that

$$\omega_1 = \frac{\Theta\mu}{1_Q'\Theta\mu} = \frac{G^{-1}\alpha}{1_Q'\Theta\mu} \quad (4)$$

$$\omega_2 = \frac{\Theta 1_Q}{1_Q'\Theta 1_Q} = \frac{-G^{-1}\delta}{1_Q'\Theta 1_Q}, \quad (5)$$

where $\delta = (\delta_1, \ldots, \delta_Q)'$.

According to the two-fund separation theorem, any efficient portfolio can be decomposed as a weighted average of these two portfolios. Therefore, $\alpha_q = 0$ and $\delta_q = 0$ are necessary and sufficient conditions for the mean-variance spanning of asset q by the other $Q-1$ assets. The other assets are called benchmark assets, while asset q is called the test asset.

More specifically, when $\alpha_q = 0$, asset q receives a zero weight in the mean-variance portfolio. Testing H_0: $\alpha_q = 0$, which is known as the intersection test, consists of testing whether the addition of asset q improves the efficient frontier of the mean-variance portfolio and therefore provides a better opportunity for investors than is provided by the other $Q-1$ assets. Similarly, when $\delta_q = 0$, asset q receives a zero weight in the minimum-variance portfolio.

The results regarding the rejection of the two null hypotheses H_0: $\alpha_q = 0$ and H_0: $\delta_q = 0$ (with individual t-tests) as well as those regarding the rejection of the joint hypothesis H_0: $\alpha_q = \delta_q = 0$ (with an F-Test) are reported in Table 3. In the first and second columns, Test asset denotes the assets to be added to the benchmark portfolio and Benchmark assets denotes the assets already included in the benchmark portfolio. The third and fourth columns show the estimated intercepts α_q and δ_q, respectively, i.e., the sum of the β coefficients. One, two or three asterisks to the right of the estimated coefficients indicate their significance at the 10%, 5% and 1% significance levels, respectively. The fifth and the sixth columns show the F-test statistic for the null hypothesis H_0: $\alpha_q = \delta_q = 0$ and its p-value, respectively.

In the context of the threshold approach (Panels A and B), we find that the spanning hypothesis is rejected for the small- and large-cap stocks at the 5% significance level and in some cases even at the 1% significance level. For the other classification methods, the null spanning hypothesis is rejected for the extreme size-based portfolio categories, i.e., for the micro-cap and very large-cap stocks. However, the spanning hypothesis is never rejected for mid-cap stocks. The spanning test, therefore, shows that investors may benefit from the addition of micro- or small-cap stocks to their portfolios. Looking at the individual tests, we can conclude that the addition of any of the tested assets to the benchmark portfolios that consist only of French stocks does not significantly change the tangency portfolio because none of the α_q coefficients are statistically significant.

To account for international diversification, we also employ the mean-variance spanning test for the benchmark portfolios, including the international large-cap indices. The results of the mean-variance spanning test, accomplished through the consideration of French size- based portfolios as test assets, are reported in Table 4. Except for the first decile in the case of the decile method (which represents micro-cap stocks), we find strong indicators that the spanning hypothesis should be rejected for all the size-based portfolios regardless of the approach used to form them. This means that the inclusion of French assets improves the mean-variance of an efficient portfolio regardless of the size of these assets (small-, mid- or large-cap). Furthermore, the rejection of the spanning test exhibits greater statistical significance for small- and mid-cap stocks than it does for large-cap stocks,(micro-caps are excluded for the quartile, quantile and decile portfolios).

An examination of the individual significance of the α_q coefficients also reveals interesting findings. Indeed, while α_q was found to be insignificant in all the cases shown in Table 3, we see that once international large-cap indices are included in the benchmark portfolios, the addition of small- and even middle-cap French assets allows us to improve the efficient frontier of the tangency portfolio most of the time. Small- and middle-cap French stocks, therefore, not only allow us to reduce the variance of the minimum-variance portfolio (i.e., when $H_0 : \delta = 0$ is rejected) but also to increase its Sharpe ratio.

More specifically, we see in Panel A of Table 4 that the inclusion of small- and mid-cap French stocks in the internationally diversified portfolio allows us to improve its Sharpe ratio and to decrease its variance, whereas the inclusion of only large-cap French stocks allows us to decrease the portfolio variance but not to improve the Sharpe ratio.

As a robustness check, we complement our analysis by performing spanning tests using the returns observed over 90-month rolling windows. Figure 2 depicts the p-value of the mean-variance spanning test (i.e., H_0: $\alpha_q = \delta_q = 0$) over the period spanning from July 2007 to December 2018 for the threshold approach and corresponds to Panel A in Table 4[81]. Several findings emerge from this figure. First, regarding the size premium, we see a large amount of variability over time in the spanning test results of the three

[81] Similar figures for the other four approaches are not presented to save space but are available upon request.

portfolios. Second, the spanning hypothesis cannot be rejected at the 5% level for small-, mid- and large-cap portfolios during the period spanning from 2007-2012, except for the period of 2007-2008, during which the large-cap stocks behaved like an asset class (this time period corresponded with the beginning of the financial crisis). Recall that the p-values reported for time *t* correspond to the p-values of the spanning test computed over the past 90 months up until month *t*. Third, beginning at the end of the financial crisis in 2012 and until 2018, the spanning hypothesis is always rejected at the 1% level for the small-cap portfolios relative to an investment set consisting of both mid- and large-cap portfolios. These results are consistent with Switzer (2010)[82], who finds that small-cap firms outperform large-cap firms during the year subsequent to an economic trough but tend to lag the year prior to a business cycle peak.

Figure 2: P-values of the mean-variance spanning test on rolling windows of 90 months

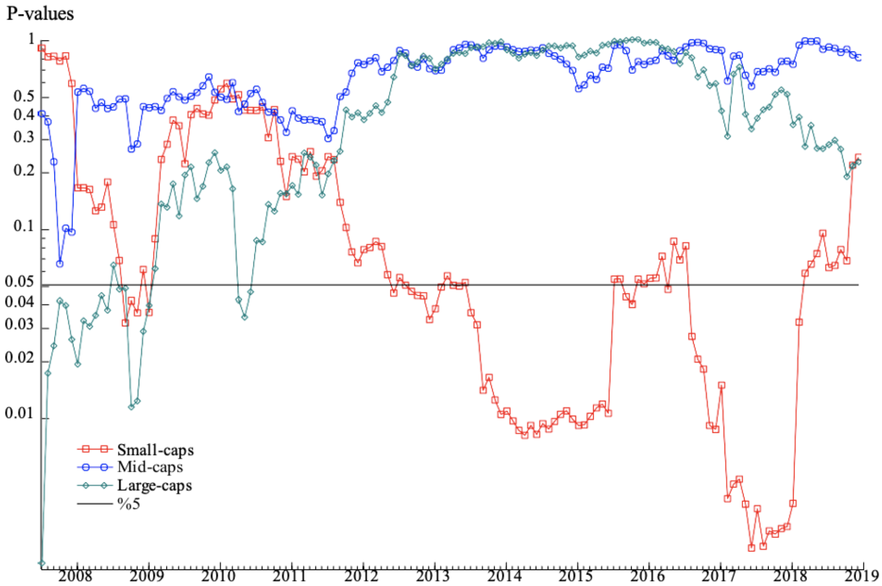


Table 3: Mean-variance spanning tests for size-based portfolios
This table reports the results of mean-variance spanning tests for size-based portfolios. Threshold portfolio classification is denoted as Mi, S, M and L for micro-cap, small-cap, mid-cap and large-cap portfolios, whereas quartile portfolio classification is denoted $4Qx$ with $x = 1, \dots, 4$, quantile portfolio classification as $5Qx$ with $x = 1, \dots, 5$ and decile portfolio classification as $10Qx$ with $x = 1, \dots, 10$. Test asset indicates the asset to be tested and Benchmark assets the assets already included in the benchmark portfolio. The last two columns are the statistic and the corresponding p-value of the mean-variance spanning test $H_0 : \alpha_q = \delta_q = 0$. The test statistic is a standard Fisher test statistic of linear restriction with 2 and T Q degrees of freedom. The sample period is January 2000 to December 2018.

[82] L. Switzer, *The behavior of small-cap vs. large-cap stocks in recessions and recoveries: empirical evidence for the United States and Canada*, cit., p. 332 ss.

Test assets	Benchmark assets	α_q	δ_q	F-Stat	p-value
Panel A: Threshold Approach					
S	M+L	0.0007	-0.0569**	3.1234	0.0459
M	S+L	0.0006	-0.0082	0.2593	0.7718
L	S+M	-0.0015	-0.1001***	5.8290	0.0034
Panel B: Threshold Approach including Micro Caps					
Mi	S+M+L	0.0018	-0.1618***	11.1952	0.0000
S	Mi+M+L	-0.0002	0.0110	0.1079	0.8978
M	Mi+S+L	0.0007	-0.0067	0.2619	0.7698
L	Mi+S+M	-0.0014	-0.1107***	6.5693	0.0017
Panel C: Quartile portfolios					
4Q1	4Q2+4Q3+4Q4	0.0016	-0.1223**	2.3130	0.1013
4Q2	4Q1+4Q3+4Q4	0.0017	-0.0708***	4.5025	0.0121
4Q3	4Q1+4Q2+4Q4	-0.0002	0.0128	0.1796	0.8357
4Q4	4Q1+4Q2+4Q3	-0.0012	-0.1240***	7.5210	0.0007
Panel D: Quantile portfolios					
5Q1	5Q2+5Q3+5Q4+5Q5	0.0020	-0.1835***	3.4165	0.0346
5Q2	5Q1+5Q3+5Q4+5Q5	0.0017	-0.1242**	5.2581	0.0059
5Q3	5Q1+5Q2+5Q4+5Q5	0.0003	-0.0301	1.1173	0.3290
5Q4	5Q1+5Q2+5Q3+5Q5	0.0001	0.0315**	1.4670	0.2328
5Q5	5Q1+5Q2+5Q3+5Q4	-0.0009	-0.1476***	10.4931	0.0000
Panel E: Decile portfolios					
10Q1	10Q2+10Q3+10Q4+10Q5+10Q6+10Q7+10Q8+10Q9+10Q10	-0.0045	-0.2805***	5.1649	0.0064
10Q2	10Q1+10Q3+10Q4+10Q5+10Q6+10Q7+10Q8+10Q9+10Q10	0.0050	0.2805**	2.1791	0.1156
10Q3	10Q1+10Q2+10Q4+10Q5+10Q6+10Q7+10Q8+10Q9+10Q10	0.0036	-0.0277	0.6436	0.5264
10Q4	10Q1+10Q2+10Q3+10Q5+10Q6+10Q7+10Q8+10Q9+10Q10	-0.0005	-0.1640***	9.8392	0.0001
10Q5	10Q1+10Q2+10Q3+10Q4+10Q6+10Q7+10Q8+10Q9+10Q10	0.0020	-0.0250	1.1162	0.3294
10Q6	10Q1+10Q2+10Q3+10Q4+10Q5+10Q7+10Q8+10Q9+10Q10	-0.0011	-0.0173	0.8283	0.4382
10Q7	10Q1+10Q2+10Q3++10Q4+10Q5+10Q6+10Q8+10Q9+10Q10	0.0010	0.0152	0.6921	0.5016
10Q8	10Q1+10Q2+10Q3++10Q4+10Q5+10Q6+10Q7+10Q9+10Q10	- 0.0007	0.0149	0.3692	0.6917
10Q9	10Q1+10Q2+10Q3++10Q4+10Q5+10Q6+10Q7+10Q8+10Q10	0.0007	0.0663***	3.9384	0.0209
10Q10	10Q1+10Q2+10Q3++10Q4+10Q5+10Q6+10Q7+10Q8+10Q9	-0.0013	-0.1600***	15.4625	0.0000

Table 4: Mean-variance spanning tests of the international benchmark assets
This table reports the results of the mean-variance spanning tests of the size-based portfolios. The symbol “o” in the column labeled benchmark assets indicates that, in addition to the listed portfolios that include large-cap stocks, we also consider the MSCI large-cap indices of the following countries in the composition of the original investment portfolio: Australia, Canada, Germany, Hong Kong, Italy, Japan, the Netherlands, the United Kingdom and the USA. See the note in Table 3 for more details.

Test assets	Benchmark assets	a_q		δ_q		F-Stat	p-value
Panel A: Threshold Approach							
S	L+0	0.0045	**	- 0.2038	***	7.5377	0.0007
M	L+0	0.0035	**	- 0.1724	***	8.3878	0.0003
L	0	0.0015		- 0.0567	**	3.2730	0.0398
Panel B: Threshold Approach including Micro Caps							
Mi	L+0	0.0054	**	- 0.2845	***	9.3623	0.0001
S	L+0	0.0041	**	- 0.1919	**	6.2412	0.0023
M	L+0	0.0035	**	- 0.1724	***	8.3878	0.0003
L	0	0.0015	*	- 0.0567	**	3.2730	0.0398
Panel C: Quartile portfolios							
4Q1	4Q4+0	0.0063	*	- 0.3006	***	5.3444	0.0054
4Q2	4Q4+0	0.0049	**	- 0.1949	***	7.5525	0.0007
4Q3	4Q4+0	0.0035	*	- 0.1394	***	5.2272	0.0061
4Q4	0	0.0017	*	- 0.0618	**	3.9129	0.0214
Panel D: Quantile portfolios							
5Q1	5Q5+0	0.0066		- 0.2423	**	3.1119	0.0465
5Q2	5Q5+0	0.0047	*	- 0.2727	***	7.6909	0.0006
5Q3	5Q5+0	0.0038	*	- 0.1796	**	6.3092	0.0022
5Q4	5Q5+0	0.0033	*	- 0.1183	**	3.9904	0.0199
5Q5	0	0.0016	*	- 0.0604	**	3.7130	0.0260
Panel E: Decile portfolios							
10Q1	10Q10+0	0.0013		- 0.0807		0.4288	0.8404
10Q2	10Q10+0	0.0104	**	- 0.4344	**	2.5744	0.0008
10Q3	10Q10+0	0.0067	*	- 0.2719	***	0.4729	0.0095
10Q4	10Q10+0	0.0045	*	- 0.3142	***	2.9551	0.0001
10Q5	10Q10+0	0.0059	***	- 0.1789	**	0.9192	0.0014
10Q6	10Q10+0	0.0032		- 0.1971	**	1.1466	0.0032
10Q7	10Q10+0	0.0051		- 0.1573	**	0.5856	0.0021
10Q8	10Q10+0	0.0030		- 0.1203	**	0.3928	0.0349
10Q9	10Q10+0	0.0035	**	- 0.0004		3.9246	0.0810
10Q10	0	0.0015		- 0.0648	**	2.3707	0.0334

5. In this paper, we examine the potential of small- and mid-cap stocks to act as vehicles for portfolio diversification. The issue that we address in this paper is whether French small- and mid-cap stocks can be considered as an alternative asset class that allows for the enhancement of the mean-variance characteristics of an investor's portfolio. To this end, we first use different approaches to form size-based portfolios that include small-, mid- and large-cap French stocks, and then we expand our analysis to international portfolios.

Using the mean-variance spanning approach, several insights emerge from our analysis. First, the empirical results show that important benefits of diversification can be realized through size diversification. Second, related to the first point, French micro- and small-cap stocks cannot be spanned by mid- and large-cap stocks. This result confirms that investors may benefit from the addition of micro- or small-cap stocks to their portfolios. Third, when we employ international stock market indices as benchmark assets, we find that the inclusion of small- and mid-cap French stocks in this portfolio improves its Sharpe ratio and decreases its variance, whereas the inclusion of only large-cap French stocks decreases the portfolio variance but does not improve the Sharpe ratio. Third, the application of rolling-window methodology to the mean-variance spanning test allows us to highlight a large amount of variability over time in the test results. Except in the case of large-cap stocks at the beginning of the financial crisis, the spanning hypothesis cannot be rejected for small-, mid- or large- cap portfolios during the period spanning from 2007-2012, but this hypothesis is rejected for all the small-cap portfolios over the period spanning from 2012-2018. Our results show that the behavior of French small-cap stocks differs from that of mid- and large-cap stocks, as well as that of other international asset classes. Based on our results, we can conclude that there are benefits to investing in French small caps from the perspective of portfolio efficiency.