Contingent Convertible Bonds in Financial Networks*

Giovanni Calice † Carlo Sala ‡ Daniele Tantari §

September 2, 2020

Abstract

We study the role of contingent convertible bonds (CoCos) in a network of interconnected banks. We first confirm the phase transitions documented by Acemoglu et al. (2015) in absence of CoCos, thus revealing that the structure of the interbank network is of fundamental importance for the effectiveness of CoCos as a financial stability enhancing mechanism. Furthermore, we show that in the presence of a moderate financial shock lightly interconnected financial networks are more robust than highly interconnected networks, and can possibly be the optimal choice for both CoCos issuers and buyers. Finally our results show that, under some network structures, the presence of CoCos can increase (and not reduce) financial fragility, because of the occurring of unneeded triggers and consequential suboptimal conversions that damage CoCos investors.

Keywords: Contingent Convertible Bonds, Financial Networks, Systemic Risk, Contagion.

JEL classification: G10, G13, G14, G17.

^{*}Financial support from the AGAUR - SGR 2017-640 grant is gratefully acknowledged.

[†]School of Business and Economics, Loughborough University, Loughborough, LE11 3TU, United Kingdom. E-mail: G.Calice@lboro.ac.uk.

[‡]Department of Financial Management and Control, Univ. Ramon Llull, ESADE, Avenida de Torreblanca 59, Barcelona, Spain; E-mail: carlo.sala@esade.edu.

[§]Mathematics Department, University of Bologna, Via Zamboni 33, 40126, Bologna, Italy. E-mail: daniele.tantari@unibo.it.

1 Introduction

The 2007-2009 financial crisis has highlighted the critical role of the interbank interconnectedness for the stability of the global financial system. It also showed the importance of having access to viable short-term funding in periods of crisis, being that liquidity problems can rapidly spillover to other interconnected banks and lead to default propagation. Crucially, any default propagation, if not controlled, might then lead to systemic risks and deep economic problems. Interestingly, although the critical role of banks' liquidity has been studied prior to the financial crisis (see, among many others, e.g.: Freixas et al. (2000)), we know comparatively little about the causal implications of liquidity on banks default behaviours, and the precise mechanisms through which interbank default propagation operates in the financial system. In this regard, Andy Haldane, the Chief Economist of the Bank of England, has noted that "..to safeguard against systemic risk, the financial system needs to be managed as a system" (Haldane (2009)). In another speech, Haldane has stressed how today's financial system is heavily interconnected and raised the question on "...what might be done to close this fault-line, to improve the resilience of the international monetary system?" (Haldane (2014)). He also questioned the usefulness in the current financial system's architecture of contingent convertible bonds (CoCos),² an hybrid financial instrument introduced by regulators after the financial crisis with the aim of enhancing financial stability.

Designed to reduce the impact of a lack of short-term liquidity in times of financial distress, CoCos have been extensively issued by financial institutions in the aftermath of the 2008-2009 financial crisis, with the aim of providing a buffer in bad times. CoCos are essentially coupon-paying bonds that convert into equity shares, or are fully or partially written-off, when the issuer reaches a pre-specified level of financial distress. Hence, CoCos are regulatory instru-

¹Started with the collapse of the US real estate market and the sub-prime mortgage market, the crisis severely impacted the interbank US debt market. Due to a reduced investors' appetite for risk, overnight bank funding rates dramatically spiked to unprecedented levels, and the interbank lending market collapsed. Consequently, troubled banks found impossible to refinance their short-term debt liabilities, paving the way to a dramatic credit crunch. Credit crunch that caused several epic banks failures, such as Bearn Stearns and Lehman Brothers defaults, subsequently spilled over to the real economy. Additionally, several other systemically important financial institutions (SIFIs) had to rely on governments' support to prevent bankruptcies, at the expense of taxpayers.

²Throughout this paper we refer to CoCo and CoCos for single and multiple contingent convertible bonds, respectively.

ments designed to absorb the issuing banks unexpected future losses by means of an automatic recapitalization triggered at a pre-defined level, hence providing monetary additional loss absorbing capital to under-capitalized banks, in periods when would be otherwise difficult to raise fresh equity capital. The level of financial distress is associated with the quality of the bank's capital, and is determined by accounting values (book-value trigger), by a pre-determined price-level of the issuer's stock (market-value trigger), or by a pre-settled discretionary rule (regulatory trigger). CoCos have been so far untested in the marketplace (especially during periods of uncertainty and high volatility) despite some notable episodes of market turmoil since the financial crisis of 2008-2009. The most prominent example in recent practice is Deutsche Bank that in October 2016 experienced severe problems with its CoCos, which dropped to around 75 cents on the euro, and many other problems, including uncertainty around the power of regulators to impose losses, played a part. Moreover, investors started to believe that Deutsche Bank might default on some of its debt obligations on its CoCos, and sparked a broader sell off in European banks stocks. Evidence suggests that this decline may have determined a default propagation effect, with other major European banks experiencing a similar decline in the value of their CoCos at the same time.

In this paper, we design a balance sheet-based network to study the contagion or stability effects of CoCos within an interbank financial network. From the broadest perspective, we study whether the introduction of CoCos can effectively reduce the overall amount of systemic risk in the economy. In our setting, we model the financial system (the economy) as a network of interconnected financial intermediaries, specifically banks. More precisely, given this economy, we examine the role of CoCos and their ability to possibly mitigate the extent of default propagation that may result in systemic failures among other financial intermediaries. A crucial question we ask in this study is whether, also in presence of CoCos, interconnected systems tend to be simultaneously both stable and unstable, calm and turbulent, robust-yet-fragile (Haldane (2014), Acemoglu et al. (2015) and Gai and Kapadia (2010)). To do it, we examine the default propagation of the system in presence of shocks, the level of financial distress and the role of the CoCos equity conversion in the interbank system. The first two elements capture the mechanism of contagion propagation, by proxying the "widening" of the

shock, while the equity conversion of CoCos exemplifies the "deepening" of the shock during a financial crisis (further details in Section 2).

To examine whether and how CoCos enhance the stability of the banking sector we extend Acemoglu et al. (2015) by introducing CoCos in the financial network. Specifically, to identify which type of network may have a role in increasing or decreasing the financial stability, we propose three different financial networks: one with a low degree of interconnections (ring network), one with a high degree of interconnections (complete network) and different networks with an intermediate and always increasing degree of interconnections. A ring network is a network topology in which each bank (node) connects to exactly two other (banks) nodes, forming a single continuous pathway for signals through each node - effectively a ring. Data travels from node to node, with each node along the way handling every packet. The complete network is instead a network topology where all banks (nodes) are fully interconnected. All intermediate networks are between the ring and the complete networks. Having defined the type of interbank network, we then study how this network reacts to negative shocks in the economy and the mechanism for the propagation of shocks. More precisely, we hit the financial network simulating negative shocks of different magnitude to test the level of stability of the financial network, and whether/how contagion propagates among interconnected banks.

To shed light on the role of CoCos as financial stability instruments, we first propose the network structure without CoCos and study the stability of the network, along with other properties (Section 3). Next, we introduce CoCos in the banks' balance sheets, and analyze their effects within the financial network. Moreover, to better analyze the width and depth of the shocks in the network, we introduce CoCos in our model in two stages (Section 4). In a first step, we restrict our attention to CoCos while abstracting away from the effects of the equity conversion in the connected financial network (Section 4.2). In a second step, we assume that all the banks in the financial network can effectively use the CoCos proceeds (Section 4.2). To establish whether the specific design characterization of CoCos matter in an interbank network, we thus analyze the financial network's responses in presence of CoCos equity conversions. This double steps procedure is designed to provide a more comprehensive analysis of the role of CoCos in the propagation of shocks.

Three main results emerge from our study. First, the phase transition and the robust-vetfragile result documented by Acemoglu et al. (2015) in absence of CoCos is confirmed also in presence of CoCos. Second, we show that for the most realistic networks (the ones with an intermediate degree of interconnection) lightly interconnected networks are more robust to moderate shocks than highly interconnected ones. Notably, this result goes against the conventional wisdom that a more interconnected interbank structure enhances the stability of the financial system (Allen and Gale (2000), Freixas et al. (2000)). Finally, we document that Co-Cos are beneficial for the economy, but the type of network is of critical importance for CoCos issuers and investors and for the effectiveness of CoCos as a financial stability enhancing mechanism. More in details, we not only show the importance of the network for Cocos, but also that the introduction of CoCos in the interbank network can ultimately produce destabilizing effects due to potential adverse selection problems within banks. In the presence of moderate shocks, fully and highly interconnected networks may in fact function as sources of unneeded triggers (a trigger that is only consequence of a highly interconnected network, and not of a bank default), resulting in suboptimal conversions, thus damaging CoCos investors that will no longer receive the coupon payment. On the other hand, lightly interconnected networks may be optimal for both issuers and investors. Furthermore, for large negative shocks, the stability of the financial network with CoCos is stronger than without CoCos (vanilla case). A better understanding of these linkages is of crucial importance for the academic community, market participants and policymakers.

It is important to note that, given their nature, the configuration of CoCos is not straightforward and, to date, both academics and practitioners still disagree on how CoCos should be
structured and priced. Despite being complex products, CoCos can be fully determined by
three main elements: the trigger, the conversion ratio and how they are held before conversion. As summarized by Flannery (2014) and Greene (2016), various configurations of these
three elements may lead to very different outcomes and effects, both for the issuers and the
investors. While we recognize that the design features of CoCos is surely a theme of relevance
to the academic and policy debate, in this paper we take an "agnostic" perspective and take
the configuration as given and guided by purely practical reasons. Concretely, in this paper,

we focus on CoCos with a single book-value trigger, with equity conversion provision, which represents a considerable fraction of all CoCos issued to date. Needless to say, the same network analysis could be applied to other CoCos configuration, but would require some changes in the way conversion is triggered and executed.³

1.1 Institutional Background and Related Literature

Firstly introduced by Lloyds in November 2009, CoCos have been promoted by different regulators as a bail-in mechanism to promote banking stability and to reduce the fiscal burdens for taxpayers. Through the October 2011 reformed Capital Adequacy Rules (Basel Committee on Banking Supervision (2010)) and the November 2009 Capital Requirements Directive II (CRDII) the Basel Committee on Banking Supervision and the European Commission recognized CoCos as Tier 1 bank capital, thus making CoCos even more captivating for banks, as evidenced by the 2011-2015 boom in CoCos issuances.⁴ Using as an accounting-based trigger event like the bank's Common Equity Tier 1 (CET1), it is possible to differentiate between high and low trigger CoCos. High-trigger CoCos have a CET1-trigger level above 5.125% and, due to their capacity of reducing bank's leverage, receive an equity-like treatment by regulators. Notably, the assimilation of CoCos to debt from a fiscal viewpoint, and to regulatory capital (equity) by financial regulators, have paved the way to the emergence (and subsequent rapid growth) of a sizeable and active market for CoCos in both Europe and Asia. Low-trigger CoCos are instead normally considered as Tier 2 capital, and may lead to the orderly resolution of failed banks. Departing from this distinction Goncharenko et al. (2017) documents the connection between the issuer's characteristics and the CoCos design.

As documented by Avdjiev et al. (2020), since the Lloyd's first issuance, more than 500 billion US dollars of CoCos have been issued, with more than 400 issues by different banks in different countries.⁵ Interestingly, while for fiscal reasons in the US banks use other types of instruments

³For ease of space and clarity, in this paper we only focus on CoCos with single book-value trigger and equity conversion, and we leave the analysis of other types of CoCos as a future research.

⁴According to Moody's Investors Service (2015), the period 2011-2015 has seen an issuance of approximately more than \$300 billion CoCos with a boom for the year 2014 with an emission of \$93 and \$82 billion of Tier I and Tier II CoCos due in large part to regulatory changes that made CoCos fiscally attractive.

⁵While the majority of issuances have been in Europe (inclusive of the UK and Switzerland), other countries like China (inclusive of Hong Kong), Australia, Japan, and Canada have also issued a substantial amount of CoCos.

to boost their Tier 1 capital (e.g.: preferred stocks),⁶ US investors are net buyers of CoCos, possibly attracted by the higher yields they offer within a low-interest-rate environment. In a document for the Chairman of the U.S. House of Representatives Committee on Financial Services, Greene (2016) discusses the conditions under which the introduction of CoCos in the US capital markets may augment overall social welfare.

Our paper contributes to the broader literature on systemic risk. To the best of our knowledge, this is the first paper, with Gupta et al. (2020), that analyzes the role of CoCos in an interbank network. However, we depart from the framework in Gupta et al. (2020) and we propose a totally different network structure to describe our economy. While the very first idea of a CoCos-like product has been initially proposed by Merton (1991), the literature on CoCos begins with Flannery (2002) and Flannery (2005) which propose to use CoCos as a capitalization buffer in bad states of the economy and is surveyed in Flannery (2014). Kashyap et al. (2008) and the The Squam Lake Report (2010)⁷ discuss the role of CoCos in bank capital regulation. A recent strand of the literature discusses how the possible configurations of CoCos can lead to corporate governance problems like debt overhang, or to risk shifting/taking incentives and possible bank failures due to extreme deleveraging (Koziol and Lawrenz (2012), Hilscher and Raviv (2014), Berg and Kaserer (2011), Chan and Wijnbergen (2017), Goncharenko et al. (2017), Martynova and Perotti (2018), Albul et al. (2013), Chen et al. (2017) and Goncharenko (2019). Notice that the effective modeling and design of CoCos is still a fundamental open and unresolved research question in the academic literature. Calomiris and Herring (2013), Bolton and Samama (2012), McDonald (2013), and Pennacchi et al. (2014) develop models where Co-Cos have trigger linked to accounting values. Sundaresan and Wang (2015), Glasserman and Nouri (2016), Pennacchi and Tchistyi (2018), and Pennacchi and Tchistyi (2019) also analyze the CoCos configuration, but from a market value perspective. The incentive effects of CoCos in individual banks have been investigated by, among others, Hori and Cerón (2017).

Our paper also adds in some respects to the financial network literature. While Allen and Gale (2000) and Freixas et al. (2000) are the first theoretical papers that analyze the stability of

⁶In the US, notably due to different accounting and tax rules, there is no marketability of CoCos. The interested reader is referred to a 2012 Report published by the Financial Stability Oversight Council.

⁷As defined in their website, "The Squam Lake Group" is a non-partisan, non-affiliated group of academics who offer guidance on the reform of financial regulation". The group, made up of US academics, has been created during the 2007-2008 financial crisis, and focuses on long-term financial issues.

interconnected financial institutions through the lens of the network analysis, it is only after the 2007-2008 financial crisis that researchers started looking at the financial system through the lens of a network (e.g.: among many others: Gai and Kapadia (2010), Acemoglu et al. (2015), Acemoglu et al. (2016), Brunetti et al. (2019), Avdjiev et al. (2020)) Most of these studies explore the different designs of CoCos as well as plain vanilla financial networks, i.e.: without hybrid products like CoCos. By contrast, in this paper we focus on how CoCos interact in a financial network, thus proposing a more sophisticated (and possibly more realistic) setting of financial networks. From a policy perspective, the findings of this paper are potentially important in helping regulators better understand the role of CoCos for the stability of the financial system, and might have important implications for the optimal design and regulation of the financial system. Our results could help to better understand how policymakers might address the use of CoCos to effectively reduce the level of systemic risk in the financial system and enhance market liquidity at times of crisis.

1.2 Outline of the Paper

The remainder of the paper is organized as follows. Section 2 presents the interbank network and the repayment system of the model. Section 3 describes, still without the presence of CoCos, the ring, the complete and the intermediate financial networks. Section 4, introduces CoCos in the different networks and examines their financial stability effects. To better elucidate the role of the repayment rule in the network, we discuss the main differences between CoCos with and without equity conversion in Sections 4.1 and 4.2, respectively. Section 5 concludes. All proofs and supplemental formal results are provided in the Appendix.

2 The interbank model

In its most simplified set-up (i.e. cash $c_i = 0$) a stylized bank i's balance sheet looks like in Figure 1 where x_{ij} represents what bank j returns to bank i, s represents the bank senior obligations (e.g.: taxes, wages, money market funds) and z_i is the remaining fraction of the balance sheet not explained by the previous elements (e.g.: bank i's investments). Given this

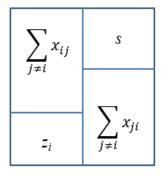


Figure 1: Bank i's balance sheet as defined in Equation (1).

framework, the bank i's balance sheet identity is:

$$\sum_{j \neq i} x_{ij} + z_i = \sum_{j \neq i} x_{ji} + s \tag{1}$$

It follows that $\sum_{j \neq i} x_{ji} = x_i \leqslant y_i$, where y_i is the face value of the inter-bank liability. Thus, when $x_i < y_i$ then bank i defaults on its junior obligations.

The presence of CoCos on the balance sheet of a bank and, more in general, any type of debt securities, creates bilateral obligations among the issuer and the owner. To analyze how these obligations affect the issuer and the owner we set up an interbank network. Banks obligations are represented as a weighted and directed graph on n nodes. Each bank in the network is represented by a node. The obligations are then represented by directed edges among nodes. Specifically, a directed edge from node i to node j exists if bank i is creditor of bank j, such that y_{ij} represents the face value of the contract among the two banks. The interbank network is thus identified by the collection of all the interbank liabilities among all banks in the network, $\{y_{ij}\}$.

Definition 2.1. Under this setting, a network is regular if $\sum_{j\neq i} y_{ij} = \sum_{j\neq i} y_{ji} = y$, i.e. everyone owes everyone the same amount.

Following Acemoglu et al. (2015), we consider a single good, finite economy with three states, t = 0, 1, 2 and n risk-neutral banks, $n < \infty$, where each bank i is endowed with an initial capital k_i . Banks cannot invest using their own fund, but can borrow money each other to finance their investments. The initial capital k can be lent to other banks, kept as cash, or invested in competitive projects. Specifically, in state t_0 the interbank lending takes place,

and banks use the money borrowed to finance their investments. The investment can produce two types of returns. A short-term t_1 stochastic return z_i , or a long-term t_2 deterministic non-pleadgeable return A, if the project is held until maturity. Also, at time t_1 banks honor their senior and interbank obligations. Due to their nature, senior obligations are nonnegative, s > 0 external obligations that are the first ones to be paid. For the interbank obligations, banks pay an interest rate R on the principal, so that the face vale of the j debt to bank i is the product of the amount borrowed and the interest rates: $y_{ij} = k_{ij}R_{ij}$. Identifying with y_i the bank's i interbank obligations, it follows that the bank i total liabilities at time t_1 are $\sum_{j\neq i}y_{ji}+s=y_i+s$. In terms of liabilities liquidation, all junior (interbank) debts have equal seniority, and are paid after the senior debts. To lighten the notation we assume $s_i=s$, for any $i=1,\ldots,n$ and $y_i=\sum_{j\neq i}y_{ji}=y$, for any $i=1,\ldots,n$ thus implying a uniform senior and inter-bank liability, respectively. Once senior debts are paid, if the company defaults, junior debts are repaid proportionally to their face values:

$$x_{ii} = \phi_i \ y_{ii}, \quad \phi_i \in [0, 1] \quad \text{for any } i, j = 1, \dots, n$$

where parameter ϕ_i is the bank fitness: if the bank i is insolvent to its junior debt then $\phi_i < 1$. Finally, if senior debts cannot be honored, junior debts are left completely unpaid. To honor their obligations at t_1 , if necessary, banks can liquidate their investments at a cost $\zeta \in [0, 1]$.

From this repayment structure it follows that all banks' obligations depend on the overall resources available to banks at time t_1 . Formally, bank i returns to bank j the amount:

$$x_{ji} = \begin{cases} y_{ji}, & \text{if } z_i + \zeta l_i + \sum_k x_{ik} > s + y_i \\ \phi_i \ y_{ji} & \text{if } z_i + \zeta l_i + \sum_k x_{ik} \in (s, s + y_i) \\ 0 & \text{if } z_i + \zeta l_i + \sum_k x_{ik} \in (0, s) \end{cases}$$
 (2)

where $l_i \in [0, A]$ represents the bank's liquidation decision:

$$l_i = \left[\min\left\{\frac{1}{\zeta}(s + y_i - h_i), A\right\}\right]^+ \tag{3}$$

where $h_i = \sum_{j \neq i} x_{ij} + z_i$ and $[\cdot]^+ = \max[\cdot, 0]$.

For the stochastic return from the investment at time t_1 , we assume it to be greater than the senior obligations in the case of no shock, $z_i = a > s$, while in the case of a shock, $z_i = a - \varepsilon$. Combining the liquidation decision, l_i with the debt repayment rule, we obtain:

$$x_{ji} = \frac{y_{iji}}{y_i} \left[\min \left[h_i + \zeta l_i - s, y_i \right] \right]^+.$$
 (4)

It is straightforward to see that when $l_i \leq A$, i.e. the project can be only partially liquidated, then $x_{ji} = y_{ji}$, thus $x_{ji} < y_{ji}$ always together with a full liquidation $l_i = A$. For this reason we can substitute in the previous repayment directly $l_i = A$ to get:

$$x_{ji} = \frac{y_{ji}}{y_i} \left[\min \left[h_i + \zeta A - s, y_i \right] \right]^+.$$
 (5)

which does not depend on the liquidation rule and can be studied independently. Finally, we can define the interbank social surplus as:

$$u = \sum_{i=1}^{n} (\pi_i + T_i)$$
$$= n(a+A) - p\varepsilon - (1-\zeta) \sum_{i=1}^{n} l_i$$

where $T_i \leq s$ is the returns to senior creditors, π_i is the bank's i profit. Denoting with $p \leq n$ the number of banks with shocks, the social surplus of the network changes and depends on the magnitude of the shocks and the liquidation value. As the liquidations decrease $\zeta \to 0$, the social surplus is solely determined by the number of defaults in the economy, i.e.:

$$u = n(a+A) - p\varepsilon - n \# \text{defaults} A \tag{6}$$

Hence, the interbank social surplus is inversely related to the number of defaults.

Equation (5) suggests that the project acts simply as an additional asset and, therefore, can be absorbed in the variable z_i . This ensures that we can study the stability properties of the banking system in the case A = 0 without loss of generality, where the debt repaying rule is

defined as:

$$x_{ji} = \frac{y_{ji}}{y} \min\left(y, z_i + \sum_{k \neq i} x_{ik} - s\right)^+. \tag{7}$$

The previous rule can be interpreted as a propagation rule for financial distress, i.e. in terms of bank's fitness it reads as:

$$\phi_i = \min\left(1, \frac{z_i - s + \sum_{k \neq i} y_{ik} \phi_k}{y}\right)^+ = f_{y,s}(h_i(\phi)), \tag{8}$$

where we have defined the activation function $f_{y,s}(h) = \min(1, \frac{h-s}{y})^+$ and the bank income $h_i(\phi) = z_i + \sum_{k \neq i} y_{ik} \phi_k$, depending on the asset side of the balance sheet and the system's amount of distress. Equation (8) can be thought either as an updating rule for fitness propagation, $\phi_i^{t+1} = f_{y,s}(h_i(\phi^t))$, or as an equilibrium defining map $F: [0,1]^n \to [0,1]^n$:

$$\phi = (\phi_1, \dots, \phi_n) \to F(\phi) = (f_{y,s}(h_i(\phi)))_{i=1}^n,$$
 (9)

which, aside from a very specific choice of the model parameters, it generally has a unique fixed point,⁸ that can be obtained numerically by simply iterating the rule from a starting point ϕ^0 (e.g.: (1, ..., 1)) until convergence.

Next, given the above framework, we investigate the properties of the equilibrium in terms of 1) *extent* of contagion:

$$E(\phi) = 1 - \frac{1}{n} \sum_{i=1}^{n} \delta_{\phi_{i},1}; \tag{10}$$

where $\delta_{\phi_i,1}$ is the Kronecker delta defined as:

$$\delta_{\phi_i,1} = \begin{cases} 1 & \text{if } i = j \\ 0 & \text{if } i \neq j \end{cases}$$

$$\tag{11}$$

and 2) system's distress:

$$D(\phi) = 1 - \frac{1}{n} \sum_{i=1}^{n} \phi_i.$$
 (12)

⁸More details in Acemoglu et al. (2015).

Moreover, we also study the financial stability of the system as a function of 1) the topological properties of the interbank directed and weighted network $Y = (y_{ij})$; and 2) the size and distribution of the shocks.

It is worth noticing how under the Acemoglu et al. (2015)'s setting, the number of negative shocks in the network, and their entity provide a way to evaluate two financial networks, for example $\{y_{ij}\}$ and $\{\widetilde{y}_{ij}\}$, in terms of stability and resilience. The former is a max-min classification, the latter is an expectation. Given p, the financial network $\{y_{ij}\}$ is more stable than $\{\widetilde{y}_{ij}\}$ if $E_p u \geqslant E_p \widetilde{u}$ (which when p=1 and for symmetric regular network implies $u \geqslant \widetilde{u}$). Given p, the financial network $\{y_{ij}\}$ is more resilient than $\{\widetilde{y}_{ij}\}$ if $\min u \geqslant \min \widetilde{u}$ (which for p=1 and symmetric regular networks implies again that $u \geqslant \widetilde{u}$). Note that under our setting, shocks are deterministic. Hence, the concepts of resilience and stability as previously defined would coincide. Interestingly, the extent of contagion proposed in Equation (10) is a proxy for financial stability and resilience under deterministic shocks. Consequently, we depart from Acemoglu et al. (2015) as we provide a novel and more general framework to analyze the behaviour of the network structure.

3 Financial Networks without CoCos

In this section, we formally introduce the structure of the networks and examine how exogenous (large and small) shocks impact on the different interbank networks. More precisely, to provide evidence on how different network connectivities may lead to different results under small and big shocks, we simulate negative shocks of different magnitude in the interbank networks described above. Note that at this stage, we still assume no CoCos in the network. CoCos will be introduced in Section 4, and the types of interbank networks - without and with CoCos - will be presented and compared. From the obtained results we also suggest some preliminary policy implications.

For the objectives of our analysis, we consider three types of regular financial networks, namely ring, complete and intermediate networks. Specifically, a financial network is a ring network if $y_{i,i-1} = y_{1,n} = y$ and $y_{ij} \neq 0$ otherwise, where n is the total number of banks. From

this configuration, bank i is the unique creditor of bank i-1, and bank 1 is the unique creditor of bank n. As a consequence of the ring structure, a default of a bank spillovers *entirely* on the subsequent banks. This property makes the ring network the least interconnected type of financial network.

A financial network is a complete network if $y_{ij} = \frac{y}{n-1} \forall i \neq j$. Under this setting, a liability and thus a possible bank default, is equally divided among all n banks in the financial network, thereby making the complete network the most interconnected type of financial network. The ring network and the fully connected network are just two extreme cases of regular networks, the first having the minimum possible connectivity ($k_{in} = k_{out} = 1$) the latter the maximal possible connectivity ($k_{in} = k_{out} = n - 1$). Finally, since we are interested in the equilibrium properties of the network in terms of extent of contagion as a function of the network connectivity, we also analyze random regular networks with different values of connectivity $k_{in} = k_{out} = c, 0 < c < \infty$. For all the intermediate networks and given their degree of connectivity (c), we again divide all the junior liabilities y of each bank in equal parts between its neighbors, i.e.:

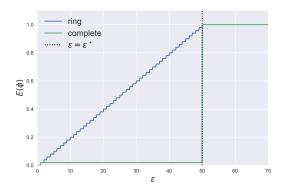
$$y_{ij} = \frac{y}{c} \delta_{i \sim j} \implies \sum_{j} y_{ij} = \sum_{j} y_{ji} = y, \quad \forall i = 1, \dots, n.$$
 (13)

We first focus on the ring and complete networks cases, and then extend our findings to the intermediate ones. The main finding of Acemoglu et al. (2015) about the stability of ring and complete financial networks given a nonnegative exogenous shock $\varepsilon > 0$ can be summarized in the following

Theorem 3.1. Given $\varepsilon^* = n(a-s)$ and $y^* = (n-1)(a-s)$, then:

- as soon as $\varepsilon < \varepsilon^*$ (small shock regime) or $y < y^*$ (low exposure regime) the extent of contagion in the ring network is larger than that in the complete network.
- as soon as $\varepsilon > \varepsilon^*$ and $y > y^*$ default becomes systemic in both the ring and the complete networks.

As shown in Appendix A, for both cases, Theorem 3.1 can be proven analytically by solving the equilibrium Equation 8 for bank fitnesses, and then comparing the extent of financial contagion.



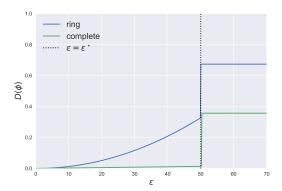


Figure 2: Simulation on ring and complete network with N = 50, a = 21, s = 20, $y = 75 > y^*$. Left panel: extent of contagion; Right panel: system's distress.

Focusing on the extent of financial contagion and on banking distress, the left and right panels of Figure 2 indicate the values of $E(\phi)$ and $D(\phi)$ as a function of the shock in the high exposure regime $(y > y^*)$, respectively. Both figures depict with a blue (green) continuous line the ring (complete) network and, dotted in black, where the contagion becomes systemic, $\varepsilon = \varepsilon^*$. Results are obtained by simulating the equilibrium in a network of N = 50 banks, with a return from the investment equal to a = 21, senior obligations s = 20 and in high exposure regime $y = 75 > y^*$. To simplify the simulation we set R = 0, thus assuming the debt to be already inclusive of any interest and, as in Acemoglu et al. (2015), we set the liquidation cost equal to $\zeta = 0$. Notably, although our focus is not directly on resilience and stability as in Acemoglu et al. (2015) we also find, for both our variables of interest, a clear phase transition between the ring and the complete networks. Therefore, these results are suggestive of at least two important policy implications. A first ex-ante recommendation, and consistent with the evidence presented in Acemoglu et al. (2015), is for regulators to enhance the regulatory oversight and the effective monitoring of the interbank interconnections (connectivity). This activity in turn would require the design and implementation of data-based measures of interconnectedness catching the degree of exposures between financial institutions. A second, ex-post recommendation, is to contain, in presence of large negative shocks, the propagation of contagion by providing financial support or even bail out the SIFIs and the too interconnected to fail financial institutions. Yet, regulators should carefully weight in the associated opportunity costs of moral hazard and incentives for excessive risk taking by banking intermediaries.

Therefore, our results strongly corroborate the view that government interventions might be beneficial (welfare improving) for the stability and efficiency of the financial network's structure (especially for a highly interconnected, such as the complete network).

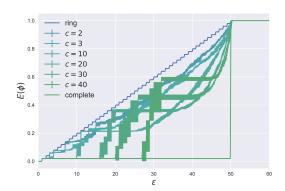
The reason for the existence of a phase transition is the presence of two types of shock absorbers in the network. The first absorber is the excess liquidity a-s>0 of the non-distressed banks. Note that the impact of a shock is less severe for banks with excess liquidity. The second absorber is represented by the claim s of senior creditors of the distressed bank. The first shock absorber perform efficiently in the complete network, while the latter is least effective in the complete network. Thus, contagion (default leading to default) is quicker with the ring network for small shocks hence, the ring network is less resilient and stable than the complete network. On the other hand, large shocks, which by definition envisage less interconnection among banks, lead to senior debts being wiped out to absorb losses. Hence, the ring network becomes as stable as the complete network thus reflecting a robust-yet-fragile framework.

Finally, we repeat the same analysis but for different intermediate network connectivity, c = 2, 3, 10, 20, 30, 40. Note that it is possible to generate randomly a regular network using the directed configuration model Bollobás (1980); Newman (2010), i.e. by considering for each node a number k_{in} (resp. k_{out}) of half in-links (resp. half out-links), and then randomly connecting each half out-link with a half in-link. A practical complication of the configuration model is that sampled networks may have self-loops and multi-edges (especially for large connectivity). These can be removed manually but, as a result, the network is not exactly regular. To limit the impact of this heterogeneity, we define the vector z of bank investments in absence of shocks as:

$$z_i = a + (y^{in} - y_i^{out}), \quad i = 1, \dots, n,$$
 (14)

where $y^{in} = \sum_j y_{ji} = y$ is the bank *i* liability, while $y_i^{out} = \sum_j y_{ij}$ is the total system liability to bank *i*, that could be different from *y*. The previously defined z_i compensates the imbalance such that each bank, in absence of shocks, has a net incoming flow *a*, as should be in a pure regular network.

The results depicted in Figure 3 are obtained by averaging over different network realizations simulated with the same degree of connectivity c. Once more, the ring and complete



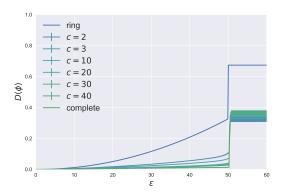


Figure 3: Simulation on Random Regular networks with N = 50, a = 21, s = 20, $y = 75 > y^*$. Results are averaged over 10 different realizations sampled from a directed configuration model. Left panel: extent of contagion; Right panel: system's distress.

networks are depicted in blue and green with a continuous line, while the intermediate networks are represented with different colors. Interestingly, we can clearly see that with an extent of financial contagion almost equal to zero, results confirm the higher stability of the complete network to small shocks, with respect to all other networks. In fact, while for the ring and all intermediate networks the extent of contagion is increasing with the shock size, the complete network experiences a systemic contagion only for $\varepsilon > \varepsilon^*$, and with a jump that determines the previously defined phase transition. Focusing on the intermediate networks, it is possible to dig deeper into the behavior of networks and their responses to shocks. Notably, our evidence indicates the existence of three and not only two regimes. More precisely, starting from the ring network and increasing the degree of connectivity, the system becomes more and more resilient, with a jump in the extent of contagion for increasing values of the shock size. The jump corresponds to the point in which the shock propagates simultaneously to all the neighbors of the stressed bank. In the limit, the network becomes fully connected, and the system is stable up to the transition point where the shock becomes systemic. It is interesting to note that there are regimes in the shock size where higher connectivity does not translate into higher stability. This implies that a more connected network is typically more stable only before the occurrence of the first jump. Afterwards, the system becomes more fragile as opposed to the case of lower connectivity.

4 Financial Network with CoCos

In this section, we repeat the same experiment of the previous section, except this time we adjust the model by introducing CoCos within the banks balance sheet structure to examine their impact on the interbank network. To provide direct evidence on the effects of the conversions, we propose the analysis for equity-conversion CoCos. To add CoCos in the bank balance sheet structure, we first finalize the bank i's initial balance sheet including the equity E_i , as illustrated in Figure 4. Thus, the bank i's balance sheet identity is modified accordingly:

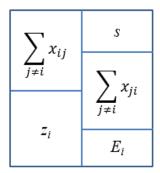


Figure 4: Bank i's balance sheet as defined in Equation (15).

$$\sum_{j \neq i} x_{ij} + z_i = \sum_{j \neq i} x_{ji} + s + E_i.$$
 (15)

As a consequence of adding equity in the analysis, the social surplus in the network is now defined as:

$$u = \sum_{i=1}^{n} (E_i + T_i). \tag{16}$$

As a second step, let $V_i = \sum_{j \neq i} x_{ij} + z_i$. Then, under this set-up, if x_{ji} were vanilla bonds with face value y_{ji} , the payoffs to each creditor are:

$$s_{i} = \min[s, V_{i}]$$

$$x_{i} = \left[\min[V_{i} - s, y_{i}]\right]^{+}$$

$$E_{i} = \left[V_{i} - s - y_{i}\right]^{+}$$

$$(17)$$

where $y_i = \sum_{j \neq i} y_{ji}$. It is worth noticing that the payoff x_i is equivalent to the Acemoglu et al. (2015) payoff for the debt repayment. Third, let all x_{ij} be CoCos with vanilla bonds represented by s.

A crucial and not trivial element in the CoCos configuration is the trigger. In his broad literature review, Flannery (2014) shows that a suitable and always valid trigger for a CoCo is:

$$\frac{P_t Q_t}{B_t} \leqslant N^{-1}(\alpha | \sigma_{A_t}) \tag{18}$$

where P_tQ_t is the firm's share price and the relative quantity, B_t the most recent book value of the assets, α the desired solvency level and σ_{A_t} the volatility of the assets portfolio. While the left hand side is a common indicator for most CoCos with a book-value trigger, the right hand side is fully discretionary. In our case, we generalize Equation 18 and consider a CoCos to be triggered whenever:

$$\frac{E_i}{V_i} \leqslant \tau \Leftrightarrow V_i \leqslant \frac{s + y_i}{1 - \tau}$$

where τ is the trigger capital ratio.

Having introduced CoCos in the bank i's balance sheet, we next examine their role within a network of banks in two steps. In Section 4.1, we first consider a network of banks with CoCos and study how and when shocks lead to a systemic CoCos triggering. Then, in Section 4.2, we explore the real effects of CoCos as a regulatory tool on the banks' balance sheets by modelling the dynamics of the actual amount of money (i.e. bonds) converted into equity in case of trigger.

4.1 CoCos Conversion

For CoCos with equity-conversion, in the case of trigger, bonds are partially or wholly converted into equity to make up (if possible) the shortfall up to $E_i = \tau V_i$. Suppose that before conversion $E_i = \bar{E}V_i$, with $\bar{E} \leqslant \tau$. The amount of bond Δy to be converted into equity is thus $\Delta y = (\tau - \bar{E})V_i$. If $y_i < \Delta y$ the entire CoCo is converted. Note that:

$$y_i < \Delta y \iff V_i - s - \bar{E}V_i < (\tau - \bar{E})V_i \implies V_i < \frac{s}{1 - \tau}.$$
 (19)

We can therefore distinguish between the following cases. First, if $\frac{s}{1-\tau} \leqslant V_i \leqslant \frac{s+y_i}{1-\tau}$, the bond is partially converted into equity, hence this implies that the CoCos holders hold $\Delta y = (\tau - \bar{E})V_i$ of converted equity and $x_i = y_i - \Delta y = (1-\tau)V_i - s$ of unconverted CoCos. Second, if $s \leqslant V_i \leqslant \frac{s}{1-\tau}$, the entire CoCo is converted. Hence, the CoCo holders hold $\Delta y = y_i$ of converted equity and no unconverted CoCo. Third, if $V_i \leqslant s$, the equity holders bear the losses before senior creditors. Combining all these cases together we obtain:

$$x_i = \min[y_i, (1 - \tau)V_i - s]^+. \tag{20}$$

Equivalently, the trigger propagation rule in terms of the banks fitness $\phi_i = x_i/y_i$ is:

$$\phi_i = f_{u,s}((1-\tau)h_i(\boldsymbol{\phi})),\tag{21}$$

with the same propagation function of the case with no CoCos. The main difference between Equation 20 and Equation 21 is in the interpretation of the fitness parameter ϕ_i . In presence of CoCos, $\phi_i < 1$, does not suggest a default, but just the triggering of the CoCo. Consequently, the distress propagation in this system indicates a triggering propagation. It is worth stressing that there is a unique equilibrium which can be derived analytically and whose property is summarized in the following theorem:

Theorem 4.1. There exist exposure thresholds $y_r^*(\tau)$, $y_c^*(\tau)$ given by Equations (38), (44) and shock thresholds $\varepsilon_r^*(y,\tau)$, $\varepsilon_c^*(y,\tau)$ given by Equations (39), (45) such that:

- when $(y,\tau) \in \mathcal{S}_r = \{\varepsilon > \varepsilon_r^*(y,\tau), y > y_r^*(\tau)\}$ the shock triggers a systemic CoCo triggering in the ring network.
- when $(y, \tau) \in \mathcal{S}_c = \{\varepsilon > \varepsilon_c^*(y, \tau), y > y_c^*(\tau)\}$ the shock triggers a systemic CoCo triggering in the complete connected network.

 \mathcal{S}_r and \mathcal{S}_c identify the systemic unstable regions for the ring and complete networks, respectively. It follows that their complement \mathcal{S}_r^c and \mathcal{S}_c^c identify the safe regions for the ring and complete networks, respectively. Moreover $\mathcal{S}_r \subset \mathcal{S}_c$ and

• when $(y,\tau) \notin S_c(implying (y,\tau) \notin S_r)$ the ring network is the least (and the complete network is the most stable) financial network.

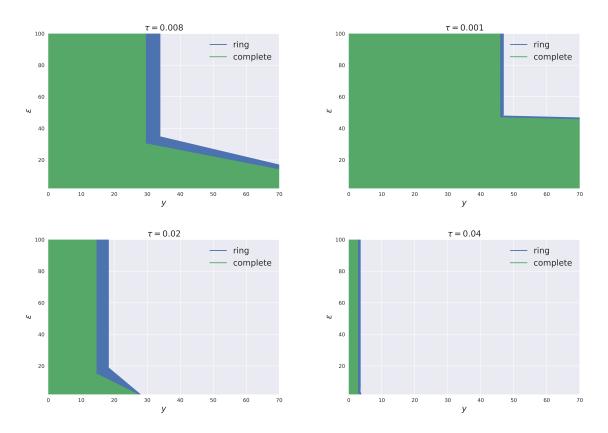


Figure 5: Safe region for the ring and the complete networks for different values of τ .

• there exist a region where $(y,\tau) \notin S_r$ but $(y,\tau) \in S_c$ where the ring network is the most (and the complete network is the least) stable financial network.

The proof is reported in Appendix B.2 and is based again on the analytical solution of the fixed point Equation (21). The first part of the theorem states that, in presence of CoCos, the unstable region (large shock and high exposure) is not universal, as in the case of vanilla bond, but strongly depends on the network structure. As a consequence of the dependence on the network structure, there are different thresholds for different levels of shock size (ε) and exposure (y). Moreover, as shown in Figure 5, the unstable regions (or equivalently the safe regions) are strongly affected by the triggering parameter τ . When τ tends to zero, CoCos become vanilla bonds, and the two regions tend to coincide. When instead τ increases, the two regions tend to diverge more and more significantly. In the second part of the theorem, the two unstable regions (for the ring and complete networks) are compared. Remarkably, it appears that the safe region for the complete network is the smallest one. This suggests that if the size

of the shock is such that it does not determine a systemic triggering in the complete network, the latter is the most stable topology (first point). However (second point), the triggering in the complete network becomes systemic for a shock size that is smaller than the one necessary for a systemic triggering in the ring network. As such, as illustrated in Figure 5 with the orange region, there exists a medium shock size region, in which the ring network is more stable than the complete one. For larger shocks, the triggering becomes systemic also in the ring network, and the two topologies are equivalently sub-optimal.

Figure 6 shows the extent of contagion and system's distress as a function of the shock size in a high exposure regime, for different network connectivity. For consistency with the previous analysis, we repeat the simulation exercise on random regular networks with N=50, a=21, s=20, y=75, and all results are averaged over 10 different realizations sampled from a directed configuration model. Again, the degrees of connectivity are equal to c=2, 3, 10, 20, 30, 40 and maintained constant throughout the simulations. As we can observe from the

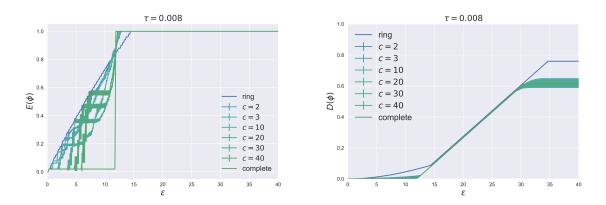


Figure 6: Simulation on random regular networks with N = 50, a = 21, s = 20, y = 75. Results are averaged over 10 different realizations sampled from a directed configuration model.

figure the system behaves as in the vanilla bond case for a shock of relatively small size. The ring network is the most resilient, the complete network the least robust and for intermediate connectivity jumps occur again, delimiting the region where the higher connectivity enables the system's robustness. Note that immediately after a jump occurs, the network enters a fragility phase where systems with lower connectivity are more robust. For medium shocks sizes, there is an inversion point, where all the lines in Figure 6 cross, after which the contagion becomes systemic in the complete network, whereas the ring network is still relatively stable.

Finally, for larger shocks sizes, all the network structures are equivalent, since they cannot prevent the triggering to become systemic. A final remark on the difference between CoCos and vanilla bonds concerns the shape of the shock size threshold $\varepsilon(y,\tau)$ which now explicitly depends on the bank exposure y (instead of τ). In particular, for both network topologies the critical threshold decreases with the exposure (the higher the exposure the smaller the safe regions) while in the presence of vanilla bond ($\tau = 0$) it is independent. An important financial stability consequence is the existence of a maximal exposure, beyond which any (even small) shock can determine the triggering of the distressed bank and can potentially lead to a systemic crisis.

4.2 CoCos with equity liquidation

As a final step, we proceed to analyze the scenario of a trigger event in which the CoCos holder bank uses the equity received from the CoCo issuer bank. Note that neglecting this monetary value would result in an overestimation of both the shock size and the degree of systemic distress or, equivalently, to underestimate the systemic crisis threshold. More specifically, in this section we document the possibility for the CoCos holder to liquidate, at a liquidation cost, the dollar amount of shares of the CoCos issuer bank received as a consequence of the trigger. Formally, if a shock in the economy leads to a trigger, the CoCo issuer bank i repays an amount x_i^{nc} of unconverted CoCo:

$$x_i^{nc} = \min[y_i, (1 - \tau)V_i - s]^+.$$
(22)

while it *converts* and uses the remaining amount x_i^c :

$$x_i^c = y_i - x_i. (23)$$

If we denote with $\eta \in [0,1]$ the effective market value of the issuer bank's share after the trigger, we can generalize the debt repaying rule as:

$$x_i = x_i^{nc} + \eta x^c = \eta y_i + (1 - \eta) \min[y_i, (1 - \tau)V_i - s]^+$$
(24)

and, equivalently, the propagation rule in terms of the bank fitness as:

$$\phi_i = \eta + (1 - \eta) f_{y,s}((1 - \tau) h_i(\phi)). \tag{25}$$

The value of η is bounded between 0 and 1, and denotes the dollar value of the converted shares. Indeed, such a value depends by many internal and external factors, like the overall quality of the bank, of the banking system and the size of the shock that affects an individual bank. Moreover, a CoCo conversion might depress the bank's equity, being a trigger usually seen as a bad signal for the bank issuer by market participants. In this paper, we treat η as exogenously given, and analyze the effects on the level of bank fitness for different values of η . First, for $\eta = 0$ (shares have zero value) the bank cannot use any money from the conversion and we indeed retrieve the results of the previous section. Second, for $0 < \eta \le 1$ the equity conversion mitigates the propagation of the shock in a non-linear way, and η becomes the minimum possible bank fitness. Figure 7 shows the extent of contagion as a function of the shock obtained by simulating the equilibrium in a network of N = 50, a = 21, s = 20, y = 75. Given this equilibrium and a fixed value $\tau = 0.008$, the left and right panels of Figure 7 show the results of the simulation for the ring (blue line), complete (green line) and intermediate networks (remaining lines) with a conversion coefficient equal to $\eta = 0.03$ (left) and $\eta = 0.3$ (right), respectively. For $\eta = 0.03$ (left panel) the ring network is more stable

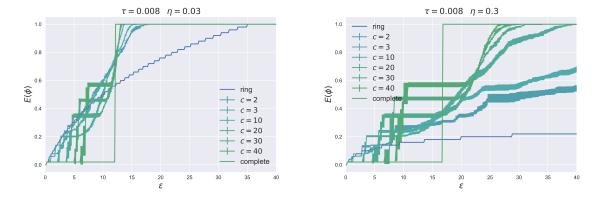


Figure 7: Simulation on Random Regular networks with N = 50, a = 21, s = 20, y = 75. Results are averaged over 10 different realizations sampled from a directed configuration model.

than both the complete network and all the intermediate ones. In fact, while the extent of contagion is systemic (=1) in the ring network for big shocks only (from $\varepsilon \geq 35$ on), the complete network is the first type of network that achieves maximal instability (for $\varepsilon \geqslant 12$), followed by the intermediate networks. With respect to the intermediate networks, the lightly interconnected ones are again more stable than the highly interconnected networks, and with a stronger magnitude than the case with no equity conversion. Unsurprisingly, the stability of the ring and lightly interconnected networks is even stronger as η increases, but in a non-linear way. As we can see from the right panel of Figure 7, for $\eta = 0.3$, the ring network is not only again the most stable network, but a) it never achieves the full extent of contagion and b) reaches the maximal extent of contagion at around $E(\phi)=20\%$ also for the largest shocks. Moreover, although the extent of contagion increases with the degree of interconnections, the change is non-linear. Therefore, the lightly interconnected networks (c = 2 and c = 3) are never susceptible to systemic contagion and reach their maximum value at $E(\phi) \approx 60\%$. Finally, for the set of medium to highly interconnected networks, the extent of contagion grows more than linearly, with the complete network showing a systemic contagion already for small shocks ($\varepsilon = 17$). Hence, our results clearly demonstrate that the equity conversion is the most beneficial for no or lowly interconnected networks and the most detrimental for highly interconnected networks. In fact, highly interconnected networks are more prone to financial contagion in presence of a CoCos trigger. Note that the estimated results depend on the choice of η , to circumvent discretionary choices and to provide a general overview of the role of η for the complete and ring networks. Figure 8 summarizes the results. Plotting the level of the critical size of the shock $\varepsilon^*(\eta,\tau) \in [0,100]$ on the y axis, and the conversion value $\eta \in [0,1]$ on the x axis, the figure clearly illustrates how in the ring network the critical size of the shock grows much faster than in the complete network. More precisely, while the complete network critical shock size has a very slow growth, for $\eta \approx 0.1$ the ring one has already exploded, meaning that for those values the ring network can never experience a systemic trigger.

As discussed so far, the complete and highly interconnected networks are more prone to CoCos conversion in presence of shocks. As illustrated in Figure 8, in fact the equity conversion resulting from the trigger might be beneficial for the banking system when the shock amplifies

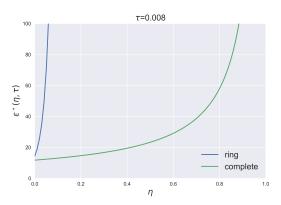


Figure 8: Critical shock for the ring and the complete network as a function of η , see Appendix C for explicit expressions.

systemic financial risk. By contrast, unnecessary conversions might actually penalize (and hit) the bond (CoCo) holders. We define the conversions to be unnecessary whenever a shock leads to a systemic conversion without creating systemic risk in the economy. To better elucidate this result, we now compare Figure 2 with Figure 8. Figure 2 shows that in absence of CoCos the risk is systemic only from $\varepsilon \geq 50$, while Figure 8 illustrates that the ring and many lightly interconnected networks experience a systemic trigger for much smaller shocks in the economy. From a market perspective, to avoid the automatic triggering below a certain threshold, CoCos issuers could consider to issue CoCos with a dual trigger conversion (e.g.: McDonald (2013)), one endogenous trigger, linked to the balance-sheet or firm's equity value, and one endogenous, controlled by the regulatory authority.

Our results have important implications for financial stability, policy analysis and welfare. A first notable implication is for policymakers and regulators to be vigilant and pursue a targeted nuanced monitoring approach on the issuance of the contracts and the way the instruments are actually managed by financial institutions, primarily by the systemically important financial institutions (SIFIs). We advocate that regulators should consider an adequate monitoring of the degree of exposure to these instruments of the SIFIs in order to mitigate possible systemic risk concerns especially in the case of highly interconnected networks of banks and/versus other financial institutions. A first specific policy recommendation is for the relevant supervisory authorities to enhance the disclosure requirements of the typology, features and amount of CoCo held by each individual bank as well as their types of interdependencies

(counterparty risk) with other banking intermediaries and non-banking financial institutions (shadow banking). A second policy recommendation is for regulators to carefully reconsider the design and the structuring of CoCos potentially incentivizing the issuance of going-concern CoCos with market-based triggers which may reduce inherent agency costs problems between banks' managers and shareholders. Nonetheless, we take an agnostic view as for the welfare effects of these instruments.

5 Conclusions

Contingent convertible bonds (CoCos) are regulatory financial instruments introduced in the aftermath of the 2008-2009 financial crisis with the aim of containing the build-up of systemic risk in the financial system in bad times. In this paper we propose different balance-sheet based interbank financial networks, with and without CoCos, and we show that the structure of the network is of great importance for the effectiveness of CoCos as risk mitigating securities. Specifically, we demonstrate that for ring and complete networks the state (phase) transition in a network without CoCos is also naturally operational in a network with CoCos, thus confirming the robust-yet-fragile result documented by Acemoglu et al. (2015). We also show that, in presence of moderate shocks, lowly interconnected networks enhance the stability of the financial system more than highly interconnected ones. Finally, we show that to maximize the effectiveness of CoCos both issuers and investors should consider the type of interbank financial network where they live. Overall, policymakers and regulators should carefully consider the role of the interbank network to assess the potential financial contagion dynamics of CoCos.

A Proof of Theorem 3.1

A.1 Ring Network

In this case $y_{ij} = y(\delta_{j,i+1} + \delta_{j,i-1})$. We can study analytically the equilibrium of the system after an idiosyncratic shock of size ε on one bank: $\mathbf{z} = (a - \varepsilon, a, \dots, a), \ a > s$ and $\varepsilon > (a - s)$. Denoting $\boldsymbol{\phi}^*$ the equilibrium we have that $\phi_1^* \leqslant \phi_2^* \leqslant \dots \leqslant \phi_n^*$. Let

$$\bar{n}(\phi^{\star}) = \max\{i : \phi_i^{\star} < 1\} \tag{26}$$

the number of insolvent banks. As soon as $\bar{n} < n$, it should be $\phi_n = 1$ and thus:

$$\phi_1 = f_{y,s}(y + a - \varepsilon)$$

$$\phi_i = \phi_{i-1} + \frac{a-s}{y} = \phi_1 + (i-1)\frac{a-s}{y}, \quad i = 2, \dots, \bar{n}$$

$$\phi_i = 1, \quad i > \bar{n}.$$

It holds as soon as $\bar{n} < n$, i.e. $f_{y,s}(y+a-\varepsilon) + (n-1)\frac{a-s}{y} > 1$, whose solution is

$$\varepsilon < \varepsilon^* = n(a-s)$$
 or $y < y^* = (n-1)(a-s),$ (27)

exactly as in Acemoglu et al. (2015). This is the equilibrium in the small shock ($\varepsilon < \varepsilon^*$) or low exposure ($y < y^*$) regime, where ε^* is the total system' liquidity in absence of shocks. In this regime the extension of the contagion is, from Equation 27,

$$E(\phi^*) = \bar{n}(\phi^*)/n = \left[1 + \frac{y}{a-s} \left(1 - f_{y,s}(y+a-\varepsilon)\right)\right]/n, \tag{28}$$

which is linearly stepwise increasing with ε until $\min(\varepsilon^*, y + (a - s))$. Analogously the total distress is

$$D(\phi) = \frac{\|1 - \phi^*\|}{n} \approx \frac{\bar{n}(\phi)(1 - \phi_1^*)}{2n}$$
(29)

which grows quadratically in ε up to the transition. On the contrary, when $\varepsilon > \varepsilon^*$ and $y > y^*$, it is $\bar{n} = n$. In this regime it should be at the same time $\phi_n = \phi_1 + (n-1)\frac{a-s}{y}$ and

 $\phi_1 = (\phi_n + \frac{a-s-\varepsilon}{y})^+$. The only possibility is that:

$$\phi_1 = 0$$

$$\phi_i = (i-1)\frac{a-s}{y}, \quad i > 1.$$

This solution is independent from ε since the distress propagation is already maximal: $E(\phi^*) = 1$ and $D(\phi^*) = 1 - \frac{(a-s)(n-1)}{2y} = 1 - \frac{1}{2} \frac{y^*}{y}$.

A.2 Fully connected network

In this case, every pair of banks is connected and the junior liability of a bank is equally distributed among its neighbors, i.e. $y_{ij} = \frac{y}{n-1}$, $\forall i \neq j$. Again, we can study analytically the equilibrium of the system after an idiosyncratic shock of size ε on one bank: $\mathbf{z} = (a - \varepsilon, a, \dots, a)$, a > s and $\varepsilon > (a - s)$. In fact, in this case all the updating rules Eq. (8) for non shocked banks have the same structure. Thus, we can make an ansatz for the equilibrium and search for a solution of the form:

$$\phi_i = \begin{cases} \phi_s & \text{if } i = 1, (\text{ shocked bank}) \\ \phi_{ns} & \text{if } i > 1, (\text{ non shocked bank}), \end{cases}$$
(30)

where (ϕ_s, ϕ_{ns}) satisfying:

$$\phi_s = f_{ys}(a - \varepsilon + y\phi_{ns})$$

$$\phi_{ns} = f_{ys}(a + \frac{y}{n-1}\phi_s + y\frac{n-2}{n-1}\phi_{ns}).$$
(31)

Equation (31) do not admit solutions if both $\phi_s, \phi_{ns} \in (0,1)$. The two possibilities are

$$\phi_{ns} = 1 \implies \phi_s = \left(1 - \frac{\varepsilon - (a - s)}{y}\right)^+$$

$$\phi_s = 0 \implies \phi_{ns} = (n - 1)\frac{(a - s)}{y} = \frac{y^*}{y}.$$
(32)

The latter is admissible as soon as $y > y^*$ and $\phi_s = 0$, implying $\varepsilon > n(a - s) = \varepsilon^*$, thus corresponding to the large shock large exposure regime. On the contrary, $y < y^*$ or $\varepsilon < \varepsilon^*$, the

first solution holds, corresponding to an equilibrium where the shocked bank is insolvent while the rest of the system has absorbed the distress. In this second case, the solution is independent from ε for $\varepsilon > y + (a - s)$, corresponding to the maximum distress that bank 1 can propagate given its (limited) debt. The extension of contagion and overall financial distress can be easily computed starting from the analytical solutions 32. In particular, their maximum values in the large shock regime are $E(\phi^*) = 1$ and $D(\phi^*) = 1 - (\frac{1 + (n-1)y^*/y}{n}) \approx 1 - y^*/y < D^{ring}$.

B Proof of Theorem 4.1

First, we need the following propositions:

Proposition B.1. In a ring network with $z = (a - \varepsilon, a, ..., a)$ it holds $\forall i = 1, ..., n - 1$

$$\phi_i^{\star} = 1 \implies \phi_{i+1}^{\star} = 1.$$

Proof. For any i = 1, ..., n - 1, $\phi_i^* = 1$ means that $((1 - \tau)a - s)/y + (1 - \tau)\phi_{i-1}^* - \delta_{i1}(1 - \tau)\varepsilon/y \ge 1$, i.e. $((1 - \tau)a - s)/y \ge 1 - (1 - \tau)\phi_{i-1}^* \ge 1 - (1 - \tau)$.]= Thus:

$$(1-\tau)\phi_i^* + \frac{(1-\tau)a - s}{y} = (1-\tau) + \frac{(1-\tau)a - s}{y} \geqslant 1,$$

implying $\phi_{i+1}^{\star} = 1$. At $\tau = 0$ the proposition is true simply because the sequence ϕ_i^{\star} is weakly increasing.

Proposition B.2. For any $b \in \mathbb{R}$, $\varepsilon \geqslant 0$ and $\lambda \in [0,1]$, given $\phi(y,\varepsilon) = (1-\tau)(1-\varepsilon/y) + b/y$, then the portion of the positive (y,ε) plane defined by the stability condition:

$$(1 - \lambda) \min(\phi(y, \varepsilon), 1)^{+} + b \frac{\lambda}{\tau y} \geqslant 1$$

is the intersection of the regions defined by $y \leqslant y_{\lambda}^{\star}$, $\varepsilon \leqslant \varepsilon_{\lambda}^{\star}(y)$ and $\varepsilon \leqslant \varepsilon^{\star}(y)$ with:

$$y_{\lambda}^{\star} = \frac{b\lambda}{\tau}$$

$$\varepsilon_{\lambda}^{\star}(y) = b\left(\frac{\lambda}{\tau} + \frac{1}{1-\tau}\right) - (y - y_{\lambda}^{\star})\left(\frac{1}{(1-\tau)(1-\lambda)} - 1\right)$$

$$\varepsilon^{\star}(y) = \frac{b - \tau y}{1-\tau}.$$

The low exposure regime is identified by y_{λ}^{\star} , the small shock regime by $\varepsilon_{\lambda}^{\star}(y)$ and the no-shock regime by $\varepsilon^{\star}(y)$, which is correctly independent from λ , encoding the network structure.

Proof. (1) If $\phi(y,\varepsilon) \geq 1$, i.e. $\varepsilon^*(y)$, then the condition is fulfilled, because $\varepsilon \geq 0$ implies $b \geq \tau y$ and the l.h.s. is a convex combination of two numbers larger than 1. (2) If $b\lambda/\tau y \geq 1$, i.e. $y \leq y_{\lambda}^*$ the condition is fulfilled simply because $(1-\lambda)\phi(y,\varepsilon)$ is always positive. This is also a necessary and sufficient condition when $\phi(y,\varepsilon) \leq 0$ (3) If $\phi(y,\varepsilon) \in [0,1]$ then we have straightforwardly the condition $\varepsilon \leq \varepsilon_{\lambda}^*(y)$, since

$$(1-\lambda)\phi(y,\varepsilon) + b\frac{\lambda}{\tau y} \geqslant 1 \implies (1-\lambda)\left((1-\tau)(1-\frac{\varepsilon}{y}) + \frac{b}{y}\right) + b\frac{\lambda}{\tau y} \geqslant 1$$

$$\implies (1-\lambda)\left((1-\tau)(y-\varepsilon) + b\right) + \frac{b\lambda}{\tau} \geqslant y$$

$$\implies y(1-(1-\lambda)(1-\tau)) + \varepsilon(1-\lambda)(1-\tau) \leqslant b\left((1-\lambda) + \frac{\lambda}{\tau}\right)$$

$$\implies (y-y^{\star}_{\lambda})(1-(1-\lambda)(1-\tau)) + \varepsilon(1-\lambda)(1-\tau) \leqslant b\left((1-\lambda) + \frac{\lambda}{\tau}(1-\lambda)(1-\tau)\right)$$

This must be a stronger condition if instead $\phi(y,\varepsilon) \ge 1$ and is also a stronger condition when $\phi(y,\varepsilon) \le 0$, since in this case

$$(1 - \lambda) \min(\phi(y, \varepsilon), 1)^+ + b \frac{\lambda}{\tau y} \geqslant (1 - \lambda)\phi(y, \varepsilon) + b \frac{\lambda}{\tau y} \geqslant 1.$$

For this reason, the desired region is just the intersection of (1), (2) and (3), together with the conditions of positive ε and y.

B.1 Ring Network

We follow the same analysis of the previous section (i.e. in absence of CoCo). Again, $y_{ij} = y(\delta_{j,i+1} + \delta_{j,i-1})$ and $\mathbf{z} = (a - \varepsilon, a, \dots, a)$. We assume no triggers in absence of shocks, i.e.:

$$\frac{E_i}{V_i} = \frac{a-s}{a+y} \geqslant \tau \implies (1-\tau)a - s \geqslant \tau y \geqslant 0.$$
 (33)

Moreover, we consider the situation where the size of the shock is at least responsible of the first bank triggering, i.e.

$$\frac{a-\varepsilon-s}{a+y} \geqslant \tau \implies \varepsilon \geqslant \varepsilon^{\star}(y,\tau) = (a+y) - \frac{s+y}{1-\tau},\tag{34}$$

where $\varepsilon^*(y, \tau)$ coincides with the no-shock threshold of Proposition B.2. Since $\phi_i^* = 1 \implies \phi_{i+1}^* = 1$, see Proposition B.1, we can define as in the previous case:

$$\bar{n}(\phi^*) = \max\{i : \phi_i^* < 1\} \tag{35}$$

as the number of non-triggered banks. As soon as $\bar{n} < n$, it should be $\phi_n = 1$ and thus:

$$\phi_{1} = f_{y,s}((1-\tau)(y+a-\varepsilon))$$

$$\phi_{i} = (1-\tau)\phi_{i-1} + \frac{(1-\tau)a-s}{y} = (1-\tau)^{i-1}\phi_{1} + \frac{(1-\tau)a-s}{y} \sum_{k=0}^{i-2} (1-\tau)^{k} \quad i=2,\ldots,\bar{n}$$

$$\phi_{i} = 1, \quad i > \bar{n}.$$
(36)

Defining $\lambda_{\tau}^{r} = 1 - (1 - \tau)^{n-1}$, this solution holds as soon as:

$$\phi_n = (1 - \lambda_\tau^r)\phi_1 + \lambda_\tau^r \frac{(1 - \tau)a - s}{\tau y} \geqslant 1.$$
(37)

The previous condition is satisfied if $y \leqslant y_r^*(\tau)$ or $\varepsilon \leqslant \varepsilon_r^*(y,\tau)$, where (Proposition B.2, with $b = (1-\tau)a - s$ and $\lambda = \lambda_\tau^r$),

$$y_r^{\star}(\tau) = \frac{\lambda_\tau^r}{\tau} \left[(1 - \tau)a - s \right] \tag{38}$$

$$\varepsilon_r^{\star}(y,\tau) = \left(\frac{\lambda_{\tau}^r}{\tau} + \frac{1}{1-\tau}\right) \left[(1-\tau)a - s \right] - \left(y - y_r^{\star}\right) \left(\frac{1}{(1-\tau)(1-\lambda_{\tau}^r)} - 1\right) \tag{39}$$

In the limit $\tau \to 0$, since $\frac{\lambda_r^r}{\tau} \to (n-1)$, we retrieve the results of the previous section $y_r^*(\tau) \to y^* = (n-1)(a-s)$ and $\varepsilon_r^*(y,\tau) \to \varepsilon^* = n(a-s)$, Figure 5. We can compute the extension of the triggering contagion as $\phi_{\bar{n}} = 1$, bringing to:

$$E(\phi^*) = \bar{n}(\phi^*)/n = \frac{\log((\phi_{\infty} - 1)/(\phi_{\infty} - \phi_1))}{n\log(1 - \tau)},$$
(40)

where $\phi_{\infty} = \frac{(1-\tau)a-s}{\tau y}$ and ϕ_1 as in 36.

B.2 Complete network

In this case, we can again make the ansatz

$$\phi_i^{\star} = \begin{cases} \phi_s^{\star} & \text{if } i = 1, (\text{ shocked bank}) \\ \phi_{ns}^{\star} & \text{if } i > 1, (\text{ non shocked bank}), \end{cases}$$

$$(41)$$

where $(\phi_s^{\star}, \phi_{ns}^{\star})$ the solution of

$$\phi_{s} = f_{ys}((1-\tau)(a-\varepsilon+y\phi_{ns}))$$

$$\phi_{ns} = f_{ys}((1-\tau)(a+\frac{y}{n-1}\phi_{s}+y\frac{n-2}{n-1}\phi_{ns}).$$

In the safe case, where the trigger doesn't propagate through the entire network, the solution must be

$$\phi_{s}^{\star} = f_{ys}((1-\tau)(a-\varepsilon+y)) \quad \phi_{ns}^{\star} = \min(1,\phi_{ns})^{+} = 1$$

$$\phi_{ns} = \frac{(1-\tau)a-s}{y} + \frac{1-\tau}{n-1}\phi_{s} + \frac{(1-\tau)(n-2)}{n-1}\phi_{ns}$$

$$= (1-\lambda_{\tau}^{c})\phi_{s} + \frac{\lambda_{\tau}^{c}}{\tau} [(1-\tau)a-s], \qquad (42)$$

where we have defined

$$\lambda_{\tau}^{c} = \frac{\tau(n-1)}{1 + \tau(n-2)}.\tag{43}$$

This solution exists if $\phi_{ns} \geqslant 1$, i.e. again using Proposition B.2 with $b = (1 - \tau)a - s$ and $\lambda = \lambda_{\tau}^{c}$, if and only if $y \leqslant y_{c}^{\star}(\tau)$ or $\varepsilon \leqslant \varepsilon_{c}^{\star}(y,\tau)$, where

$$y_c^{\star}(\tau) = \frac{\lambda_{\tau}^c}{\tau} \left[(1 - \tau)a - s \right] \tag{44}$$

$$\varepsilon_c^{\star}(y,\tau) = \left(\frac{\lambda_{\tau}^c}{\tau} + \frac{1}{1-\tau}\right) [(1-\tau)a - s] - (y - y_c^{\star}) \left(\frac{1}{(1-\tau)(1-\lambda_{\tau}^f)} - 1\right). \tag{45}$$

We have

$$\lim_{\tau \to 0} y_c^{\star}(\tau) = \lim_{\tau \to 0} y_r^{\star}(\tau) = y^{\star} = (n-1)(a-s)$$
(46)

and

$$\lim_{\tau \to 0} \varepsilon_c^{\star}(y, \tau) = \lim_{\tau \to 0} \varepsilon_r^{\star}(y, \tau) = \varepsilon^{\star} = n(a - s). \tag{47}$$

C Cocos with equity liquidation

C.1 Ring Network

Computations similar to those in the previous section bring to

$$\varepsilon_r^{\star}(\tau, \eta) = [(1 - \tau)(a + y) - (s + y)] \left(\frac{(1 - \eta)(1 - C(\eta, \tau)^n)}{C^n(\eta, \tau)(1 - C(\eta, \tau))} \right)$$
(48)

with $C(\eta, \tau) = (1 - \eta)(1 - \tau)$. In fact as soon as $\phi_n = 1$ we have $\forall i \leq \bar{n}$

$$\phi_i = \eta + (1 - \eta) f_{y,s}((1 - \tau) h(\phi_{i-1})) = A + C \phi_{i-1}$$
$$= C^{i-1} \phi_1 + A \sum_{k=0}^{i-2} C^k = C^{i-1} \phi_1 + A \frac{1 - C^{i-1}}{1 - C}$$

with $A = \eta + (1 - \eta)b/y$ and $C = C(\eta, \tau) = (1 - \eta)(1 - \tau)$. The critical threshold in the ring network is the solution of the equation $\phi_n(\varepsilon) = 1$, i.e.

$$C^{n-1}\phi_1(\varepsilon) + A\frac{1 - C^{n-1}}{1 - C} = 1 \tag{49}$$

where $\phi_1(\varepsilon) = A + C(1 - \varepsilon/y)$. Straightforward manipulations bring equation (48)

C.2 Complete Network

In the case of the complete network we have that

$$\varepsilon_c^{\star}(\tau, \eta) = [(1 - \tau)(a + y) - (s + y)] \left(\frac{n - \tau - \eta(1 - \tau)}{(1 - \eta)(1 - \tau)^2} \right). \tag{50}$$

In fact in this case the critical shock is the solution of the equation $\phi_{ns}(\varepsilon) = 1$, i.e.

$$\phi_{ns}(\varepsilon) = \eta + (1 - \eta) f_{ys}((1 - \tau)(a + \frac{y}{n - 1}\phi_s(\varepsilon) + y\frac{n - 2}{n - 1})) = 1,$$
(51)

where

$$\phi_s(\varepsilon) = \eta + (1 - \eta) \frac{(1 - \tau)(a - \varepsilon + y) - s}{y}.$$
 (52)

Solving in ε equation (50) follows straightforwardly.

D Bibliography

- Acemoglu, D., A. Malekian, and A. Ozdaglar (2016). Network security and contagion. *Journal of Economic Theory* 166, 536–585.
- Acemoglu, D., A. Ozdaglar, and A. Tahbaz-Salehi (2015). Systemic risk and stability in financial networks. *American Economic Review* 105(2), 564–608.
- Albul, B., D. M. Jaffee, and A. Tchistyi (2013). Contingent convertible bonds and capital structure decisions. Working Paper.
- Allen, F. and D. Gale (2000). Financial contagion. Journal of Political Economy 108(1), 1–33.
- Avdjiev, S., B. Bogdanova, P. Bolton, W. Jiang, and A. Kartasheva (2020). CoCo issuance and bank fragility. *Journal of Financial Economics*.
- Basel Committee on Banking Supervision (2010). Basel III: A global regulatory framework for more resilient banks and banking systems. Bank for International Settlements.
- Berg, T. and C. Kaserer (2011). Does contingent capital induce excessive risk-taking and prevent an efficient recapitalization of banks? *Systemic Risk, Basel III, Financial Stability and Regulation 2011*.
- Bollobás, B. (1980). A probabilistic proof of an asymptotic formula for the number of labelled regular graphs. European Journal of Combinatorics 1(4), 311–316.
- Bolton, P. and F. Samama (2012). Capital access bonds: contingent capital with an option to convert. *Economic Policy* 27(70), 275–317.
- Brunetti, C., J. H. Harris, S. Mankad, and G. Michailidis (2019). Interconnectedness in the interbank market. *Journal of Financial Economics* 133(2), 520–538.
- Calomiris, C. W. and R. J. Herring (2013). How to design a contingent convertible debt requirement that helps solve our too-big-to-fail problem. *Journal of Applied Corporate Finance* 25(2), 39–62.
- Chan, S. and S. V. Wijnbergen (2017). Coco design, risk shifting and financial fragility. *ECMI Working Paper No. 2*.
- Chen, N., P. Glasserman, B. Nouri, and M. Pelger (2017). Contingent capital, tail risk, and debt-induced collapse. *The Review of Financial Studies* 30(11), 3921–3969.

- Flannery, M. J. (2002). No pain, no gain? effecting market discipline via "reverse convertible debentures". Working Paper.
- Flannery, M. J. (2005). In Capital Adequacy Beyond Basel: Banking, Securities, and Insurance, chapter 5, 171–196. Oxford University Press.
- Flannery, M. J. (2014). Contingent capital instruments for large financial institutions: A review of the literature. *Annual Review of Financial Economics* 6(1), 225–240.
- Freixas, X., B. M. Parigi, and J.-C. Rochet (2000). Systemic risk, interbank relations, and liquidity provision by the central bank. *Journal of Money, Credit and Banking* 32(3), 611–638.
- Gai, P. and S. Kapadia (2010). Contagion in financial networks. *Proceedings of the Royal Society A:*Mathematical, Physical and Engineering Sciences 466 (2120), 2401–2423.
- Glasserman, P. and B. Nouri (2016). Market-triggered changes in capital structure: Equilibrium price dynamics. *Econometrica* 84(6), 2113–2153.
- Goncharenko, R. (2019). Fighting fire with gasoline: CoCos in lieu of equity. SSRN Working Paper.
- Goncharenko, R., S. Ongena, and A. Rauf (2017). The agency of CoCo: Why do banks issue contingent convertible bonds? SSRN Electronic Journal.
- Greene, R. W. (2016). Understanding CoCos: What operational concerns and global trends mean for U.S. policymakers. *M-RCBG Associate Working Paper No. 62*.
- Gupta, A., R. Wang, and Y. Lu (2020). Addressing systemic risk using contingent convertible debt a network analysis. *European Journal of Operational Research*.
- Haldane, G. (2009).Rethinking the financial network. Speech de-Α. livered theFinancialStudentAssociation. Amsterdam.Availableat:http://www.bankofengland.co.uk/archive/Documents/historicpubs/speeches/2009/speech386. pdf.
- Haldane, A. G. (2014). Managing global finance as a system. In Maxwell Fry Global Finance Lecture.
- Hilscher, J. and A. Raviv (2014). Bank stability and market discipline: The effect of contingent capital on risk taking and default probability. *Journal of Corporate Finance* 29, 542–560.
- Hori, K. and J. M. Cerón (2017). Contingent convertible bonds: payoff structures and incentive effects.

 Birkbeck Working Paper 1711.

- Kashyap, A. K., R. G. Rajan, and J. C. Stein (2008). Maintaining stability in a changing financial system. In *Rethinking Capital Regulation, Economic Symposium*.
- Koziol, C. and J. Lawrenz (2012, Jan). Contingent convertibles. solving or seeding the next banking crisis? *Journal of Banking & Finance* 36(1), 90–104.
- Martynova, N. and E. Perotti (2018, Jul). Convertible bonds and bank risk-taking. *Journal of Financial Intermediation* 35, 61–80.
- McDonald, R. L. (2013). Contingent capital with a dual price trigger. *Journal of Financial Stabil*ity 9(2), 230 – 241.
- Merton, R. (1991). Distress-contingent convertible bonds: A proposed solution to the excess debt problem. *Harvard Law Review* 104(8), 1857–1877.
- Moody's Investors Service (2015). CoCo monitor database. Third quarter.
- Newman, M. (2010). Networks: An introduction. Oxford University Press.
- Pennacchi, G. and A. Tchistyi (2018). Contingent convertibles with stock price triggers: The case of perpetuities. *The Review of Financial Studies* 32(6), 2302–2340.
- Pennacchi, G. and A. Tchistyi (2019). On equilibrium when contingent capital has a market trigger: A correction to sundaresan and wang journal of finance (2015). The Journal of Finance 74(3), 1559–1576.
- Pennacchi, G., T. Vermaelen, and C. C. P. Wolff (2014, Jun). Contingent capital: The case of coercs.

 Journal of Financial and Quantitative Analysis 49(3), 541–574.
- Sundaresan, S. and Z. Wang (2015, Mar). On the design of contingent capital with a market trigger. The Journal of Finance 70(2), 881–920.
- The Squam Lake Report (2010). An expedited resolution mechanism for distressed financial firms: regulatory hybrid securities, the squam lake report fixing the financial system. Working Group on Financial Regulation.