Cascades of Losses from Financial Shocks in the International Cross-Holdings Network

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1 Introduction

This paper aims to examine the cascading effects of financial shocks at a macroeconomic level in a network of interconnected countries. Building upon the framework presented in Elliott, Golub, and Jackson 2014, which focused on microeconomic interconnections between individual firms, our objective is to adapt this model to analyze real-world financial interdependencies between countries. We present a theoretical analysis that captures the essence of the model, adjusting the variables to reflect the macro approach per country. Specifically, we investigate how a shock in the aggregate market capitalization of companies in a country can trigger a cascade of real losses that impact the profits (and market values) of other economies in the network. To assess the magnitude and implications of such shocks, we conduct simulations and analyze the resulting dynamics, shedding light on the systemic risks and vulnerabilities within the interconnected financial landscape.

2 Motivation

The main feature of the model lies in the incorporation of real-world financial interdependencies between countries. For example, a decrease in the U.S. market value can ripple across the financial network and influence the French market, given the substantial investments held by French companies in U.S. assets. This financial interconnectedness implies, for example, that an exogenous drop in the market values of U.S.companies can diminish the market values and profits of French companies due to their exposure to the U.S. economy through their investments in U.S. assets. Potentially, this means that purely financial shocks occurring in a country are able to induce real losses in other countries, causing a so-called financial contagion. Moreover, if decreased profits reflect also in a decreased market value in the “infected” country, the distress can proceed further and evolve in a cascade of losses, due the network nature of international cross-holdings. The question arises: how can a financial shock on a country’s market capitalization have a real effect on profits? Because it affects:

- Investor Confidence: Decreased market values can impact investor confidence, making it more challenging for companies to raise new capital.
- Corporate Financing: With depreciated assets abroad and lower company market values, firms may find it difficult to secure loans.
- Wealth Effect: Decreased market values can reduce consumer spending, causing an economic slowdown that affects corporate profits.

- Pension Funds: Market volatility can impact pension funds, which often hold significant investments in companies. When these companies' market values drop, the funds' overall value decreases, potentially reducing profits.
- Economic Growth: Decreased market values may indicate a slowing economy, which can lead to lower profits.

The channels above mainly act within the country of first shock. In what follows, we discuss how the network nature of the problem opens to the possibility of cascades of losses affecting multiple economies after a financial shock in one country.

3 Data

We use financial network data from the IMF's biannual Coordindate Portfolio Investment Survey (CPIS). The CPIS captures cross-border portfolio investment, where portfolio investment is defined as cross-border transactions and positions involving debt or equity securities, other than those classified as direct investment or reserve assets. The survey is very comprehensive, covering over 240 countries. We use annual survey data from 2001 to 2021 for our analysis and focus on total investment across all sectors. The data can be represented as a weighted directed graph, where the edges represent cross-border financial inflows and outflows. In the next section we present some network summary statistics to better understand the data and help motivate the topic.

We source data for country-level stock market capitalisation (in USD) from the World Bank.[1] To estimate county-level corporate profits, we collect corporate tax rate and corporate tax revenue data from the OECD.[2]. Due to data availability, our analysis will be limited to 31 OECD countries (Table 1).

Country	ISO code
Australia	AU
Austria	AT
Belgium	BE
Canada	CA
Czech Republic	CZ
Denmark	DK
Finland	FI
France	FR
Germany	DE
Greece	GR

Country	ISO code
Hungary	HU
Ireland	IE
Israel	IL
Italy	IT
Japan	JP
Luxembourg	LU
Mexico	MX
Netherlands	NL
New Zealand	NZ
Norway	NO
Poland	PL

Country	ISO code
Portugal	PT
Slovakia	SK
Slovenia	SI
South Korea	KR
Spain	ES
Sweden	SE
Switzerland	CH
Turkey	TR
United Kingdom	GB
United States	US

Table 1: Available countries in the dataset.

[1] See https://data.worldbank.org/indicator/CM.MKT.LCAP.CD. For some countries, market capitalisation data was not available for the full time period. We imputed missing values by fitting a linear regression of market capitalisation on profits for each country.

[2] See https://stats.oecd.org/viewhtml.aspx?datasetcode=REV&lang=en and https://stats.oecd.org/index.aspx?DataSetCode=Table_II1

4 Exploratory Data Analysis

We now present some key summary statistics for our financial network data. First, we look at the number of active nodes in the network, where an active node represents a country that has non-zero cross-border portfolio investment inflows or outflows in a given year, and the network density, which is the ratio of existing links over the number of possible links. Based on these metrics, we see that cross-border financial connectedness has increased over time (Figure 1; Figure 2).

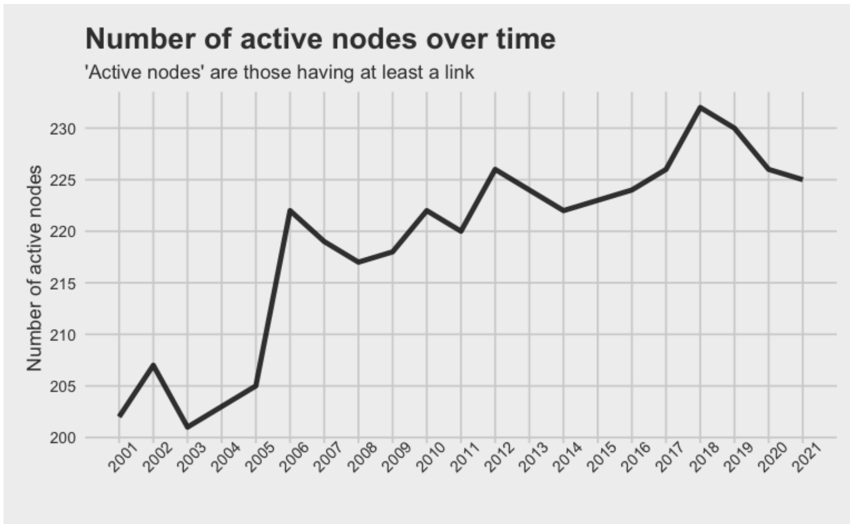

Figure 1

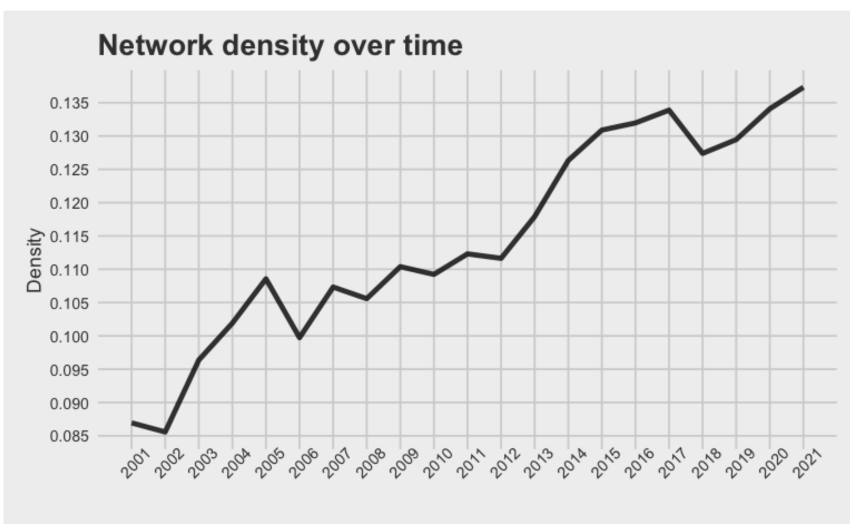

Figure 2

Figure 3 shows the total number of binary degrees, which is the sum of binary in and out degrees, for all countries in the network. We observe a large degree of variation across countries, with the US and parts of Europe having more than 200 overall binary degrees while many countries in Africa only have a few.

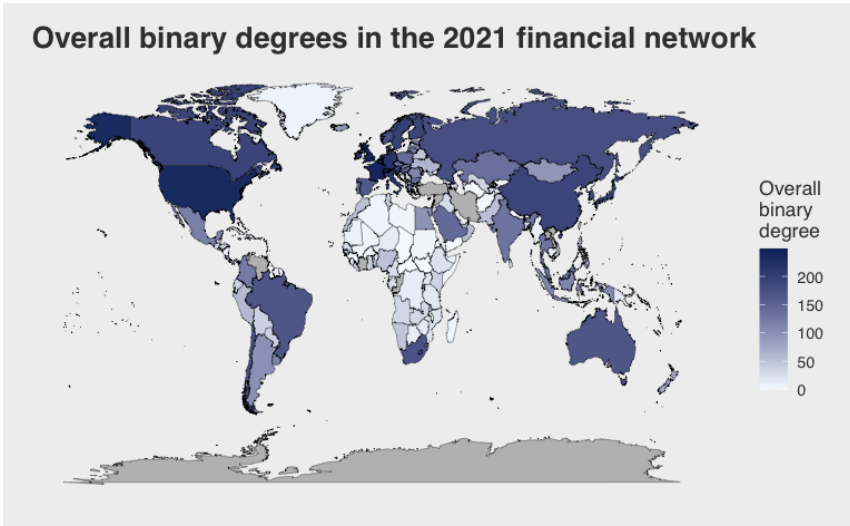

Figure 3

Figures 4 and 5 show the 18 countries with the highest "in-strength" and "out-strength" in the year 2021. The "in-strength" of country i is the sum of all cross-border portfolio investment inflows into country i. Likewise, the "out-strength" of country i is the sum of all cross-border portfolio investment outflows from country i. We observe that the US is by far the most active country in the international financial system in terms of total inflows and outflows. Also high on the list are financial hubs including Luxembourg and Hong Kong, as well as the Cayman Islands (KY), which is known as a tax haven.

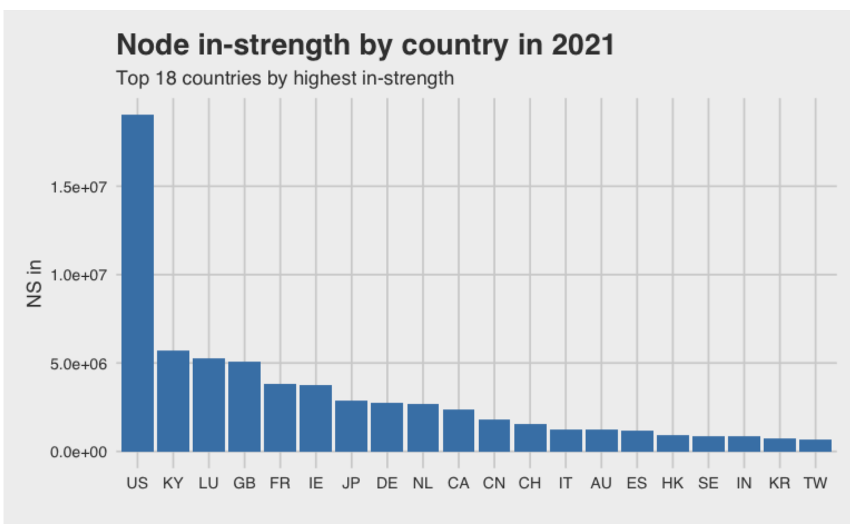

Figure 4

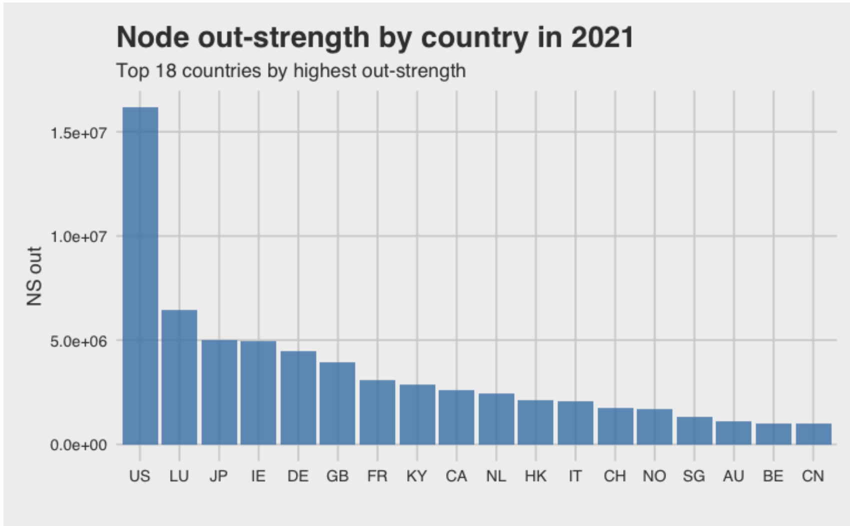

Figure 5

To better assess how important each country is in the global financial system, we compute Bonacich centralities. Figure 6 shows the top 18 countries in terms of their Bonacich centrality for 2021. The US is the most central node in the network by far, as expected. Having very central nodes in the network will have implications for the extent of financial contagion, which we will explore in our simulations.

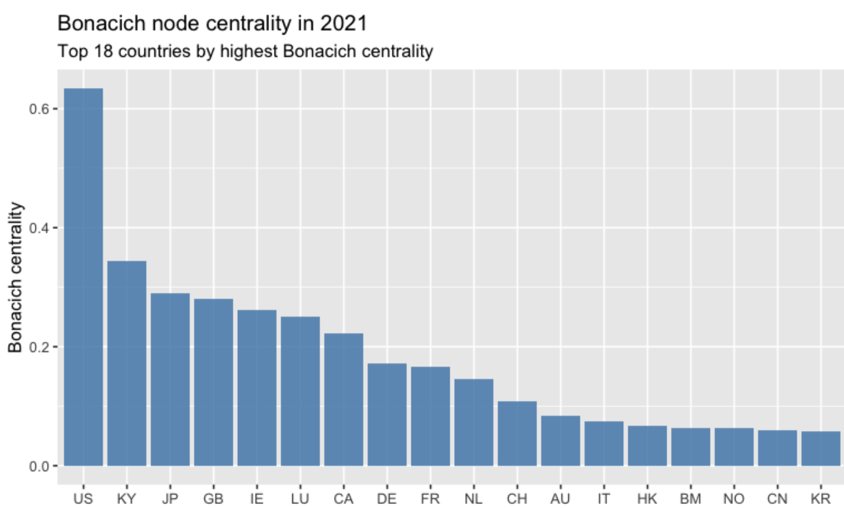

Figure 6

5 Model

We will present the macroeconomic model to examine the propagation of exogenous financial shocks through a network of financially interconnected countries. As mentioned in the introduction, the model is based on the framework presented in Elliott, Golub, and Jackson 2014 which originally focused on microeconomic interconnections between individual firms. However, instead of applying this framework at a micro level, we extend its application to a macro level to study real-world financial interdependencies between countries.

Our model comprises N countries, with each country's total market capitalization v_i reliant on the country's aggregate profit p_i and portfolio investments from other countries. These investments are captured by the weighted sum of market capitalizations v_j of other countries, with weights C_{ij}.

$$v_i = p_i + \sum_{j:i \neq j} C_{ij} v_j \tag{1}$$

In the reference paper the value of an organization is tied to its shares in primitive assets, denoted as D_{ik}, and its ownership in other organizations, represented by C_{ij}, so that $v = Dp + Cv$. In our model, however, p_i captures the total profit of a country, while C_{ij} signifies the strength of portfolio investment from one country to another. For equality to hold we introduce a daigonal matrix of scaling factors denoted as $\hat{C}$:

$$v = \hat{C}(p + Cv) \tag{2}$$

This factor $\hat{C}$ accounts for that portion of a country's market value not covered by profit. This gives us:

$$v = (I - \hat{C}C)^{-1}\hat{C}p \tag{3}$$

We define a dependency matrix $A = (I - \hat{C}C)^{-1}\hat{C}$, where each element A_{ij} quantifies the proportion of country j's failure cost borne by country i when j fails. When the aggregate market capitalization falls below a threshold $\underline{v} = (1 - \theta)v$, with $\theta \in (0, 1)$, the country suffers and additional (non-linear) cost $b_i = \beta \ 1_{v_i < \underline{v}_i} p_i$. Thus, we can rewrite the model as:

$$v = A(p - b(v, p)) = Ap - Ab(v, p) \tag{4}$$

where $b(v, p)$ denotes the vector of real costs after a severe drop in market values. These "failure costs" trigger the spreading of the contagion, as it potentially decrease the market values of other countries, propagating the shock and precipitating the system in a cascade of losses.

The cascading failures phenomenon in our model vividly demonstrates the potential consequences of even a minor shock in a network of financially interconnected countries. Let's delve deeper into this analysis, considering the impact of a shock that diminishes the profits of organization 1 from p_1 to p'_1, such that $v_1(p) > \underline{v}_1 > v_1(p')$. This decrease in profits triggers a ripple effect throughout the network, influencing other countries denoted by j through their interdependencies with organization 1, as captured by $A_{j1}\beta_1$. Consequently, the chain reaction intensifies, leading to further failures in the system. To illustrate the domino effect, imagine that the second country fails subsequent to the first country. This failure necessitates the absorption of the cumulative shock by the third country, which faces the combined failure costs of both countries: $A_{31}\beta_1 + A_{32}\beta_2$. This interplay continues, and in a more general scenario where the first K countries fail, the remaining countries must confront the cumulative failure costs of $\beta_1 + \ldots + \beta_K$. As a result, this intricate interplay of failures can easily spark a hierarchical cascade, amplifying the initial shock and exacerbating the systemic risk within the financial network.

6 Simulation results

We now pass to simulate the model using the CPIS data to account for the interdependence structure of the international financial network. The aim of the analysis is to quantify how much a shock in the aggregate market capitalization of a country can induce a cascade of losses in the market capitalization and profits of other economies.

The simulations follow Algorithm 1 and consist in first estimating the network relationships in the data, i.e. estimating $\hat{C}$ and A. Then we choose an arbitrary country i and we impose the exogenous shock b_i. Based on the estimated matrix A, we simulate the new vector of aggregate market values v resulting from the perturbed vector of aggregate profits $\tilde{p}$ after the first shock. The countries whose simulated market value falls below the $\underline{v} = (1-\theta)v$ threshold enter the cascade, and their profits are also reduced by β. The procedure is iterated until no more countries enter the cascade.

Algorithm 1 Algorithm for cascades identification

Choose a country i that endures the shock
initialize $\mathcal{Z}^{(0)} = \{i\}$ ▷ $\mathcal{Z}^{(t)}$ = set of countries in cascade at step t
initialize $b^{(0)} = (b_i)_{i=1,\dots,N}$, with $b_i = \beta \; 1_{i \in \mathcal{Z}_{t-1}}$
initialize $\underline{v} = \theta v$ ▷ Vector of threshold market values
while $\mathcal{Z}^{(t)} \neq \mathcal{Z}^{(t-1)}$ **do**
    $t \leftarrow t+1$
    $\tilde{p}^{(t)} \leftarrow A(p - b^{(t-1)})$ ▷ simulated profits after shock and cascade
    $\mathcal{Z}_t \leftarrow \{k : \tilde{p}_k^{(t)} \leq \underline{v}_k\}$
end while
return $\mathcal{Z}_0, \mathcal{Z}_1, \dots, \mathcal{Z}_t$

A nice feature of the algorithm is that it allows to study not only how many countries failed overall after a shock, but also to study the precise order of failures after different waves of feedback shocks. Indeed, the countries that fail in a new wave, $\mathcal{Z}_t \setminus \mathcal{Z}_{t-1}$, are those that would not have failed if it were not for the t-th order network effects that propagate the shock among different macroeconomies. In this way, it is possible to study the full propagation mechanism of the shock in the network. The model then allows to comapre different scenarios, like shocks hitting different initial countries i, with different intensities β_i and propagating at different thresholds θ. In particular, we run the simulations considering shocks in different countries on grid of values for two key parameters:

- i = country of first shock. Here we consider $i \in \{U.S., U.K., Spain, Italy, Germany, France\}$.
- β = percentage decrease in profits after a shock. Here we consider $\beta \in (0.01, 0.05, 0.1, 0.25)$.
- θ = threshold for the loss in aggregate market capitalization. If the market capitalization of country i after a shock in any other country j falls below $(1-\theta)V_i$ then the shock propagates and country i's profits are decreased by βP_i. Here we consider $\theta \in (0.07, 0.13, 0.20)$, as these are the circuit-breakers points established by the U.S. market volatility rules.[3]

Figures 7 and 8 reports the results of the simulations. Figure 7 reports the total number of countries that endure drops in aggregate profits in the cascade. Results for different scenarios are in line with expectations. The number of countries involved in the cascade increases with the magnitude of the profit

[3]Circuit-breakers are the thresholds at which trading is halted market-wide for single-day declines in the S&P 500 Index. They are set at 7%, 13%, and 20% of the closing price for the previous day. Source: New York Stock Exchange, Rule 80B, p. 295.

Round	Year				
	2006	2009	2011	2013	2018
1	BE, CZ, PT (3)	CZ, PL (2)	AT, BE, DK, FI, GR, HU, IE, KR, LU, MX, NL, NZ, NO, SK, CH, TR, IL, SI (18)	HU, PL, SI (3)	AT, CZ, FI, GR, HU, SK, ES (7)
2	AU, AT, DK, FI, GR, IE, KR, LU, MX, NL, NZ, NO, PL, ES, SE, CH, IL (17)	AT, DE, SK (3)	CZ, DE, PL, PT, ES (5)	AT, BE, CZ, FR, DE, SK (6)	AU, DK, IE, KR, LU, MX, NL, NO, SE, CH, TR, IL, SI (13)
3	FR, SK (2)	GR, NZ, SE, TR (4)		CA, JP, ES, GB, **US** (5)	
4				AU, DK, FI, IE, KR, LU, MX, NL, NZ, NO, SE, CH, TR, IL (14)	

Table 2: Cascades of losses in selected years after a shock in Italy, $\beta = 5\%,\ \theta = 13\%$.

loss β, as a higher loss in a country's aggregate profits is likely to reduce the market capitalization of its neighbours in the financial network. This loss can make the capitalization of a new set of countries fall below the threshold and spread the contagion. New profit losses get more likely when the shock is able to spread at lower thresholds for the drop in aggregate capitalization. As it is arguable from the model and confirmed by the simulations, in the conservative scenario where only a (dramatic) 20% loss in aggregate capitalization leads to an exogenous fall in profits less countries are involved in the cascade. However, the responsiveness of the network to shocks increased over time, and more countries would have been involved in the contagion if a shock hit a country in the last years of the sample. This result is consistent with the stylized facts in Section 2 and suggests that the higher interconnectedness of the financial network actually induced a higher fragility of the system to exogenous shocks.

A non-trivial result that we get from Figure 7 is that the cascade of losses is not in one-to-one relation with network statistics like the Bonacich centrality or the node-strengths. For instance, Italy is much less central and it is a much weaker node than the United Kingdom, Germany and France, but still induces a cascade of failures that is similar to that of most central nodes like the US (and is in some cases even higher, especially in the last years of the sample). This result can be further specified by studying the hierarchy of the cascades reported in Figure 8. In particular, we can notice that the mechanics of the propagation of the shocks is heterogenous across countries. When a shock affects the U.S. macroeconomy, a large number of countries is affected in the first round, because almost every country has large investments and is directly connected to the U.S. The contagion then usually stops and almost never goes beyond a second wave of profit losses, as all the connections between the remaining countries are not as strong as those with the U.S. In the puzzling case of Italy mentioned above, the transmission mechanism is the opposite. Few countries are usually involved in the first round of losses, but the propagation lasts sometimes for even four rounds, ending up involving a large number of countries. This is an interesting case where indirect network effects make a node of secondary importance have an impact as large as those of the central players. However, it is also worth noticing that the countries involved in the waves (reported, for the Italian case and selected years, in Table 2) are usually secondary countries in the network and usually the cascade does not involve the biggest player, even if there are exceptions like in the simulation for 2013.

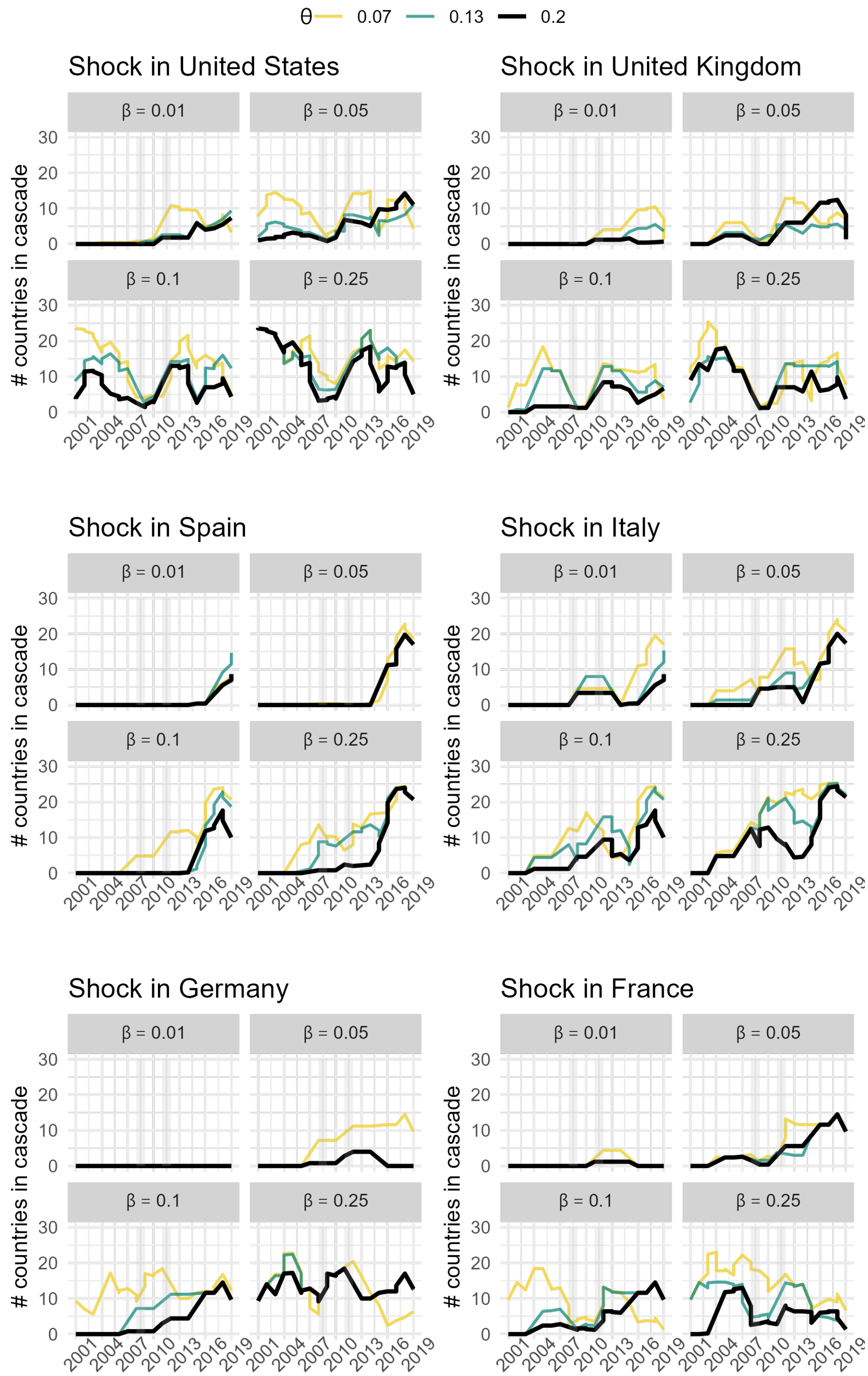

Figure 7: Cumulated failures in cascade for each year available in the sample. The values in the plot are a smoothed moving-average window of the results of the year under consideration, the next and the past year.

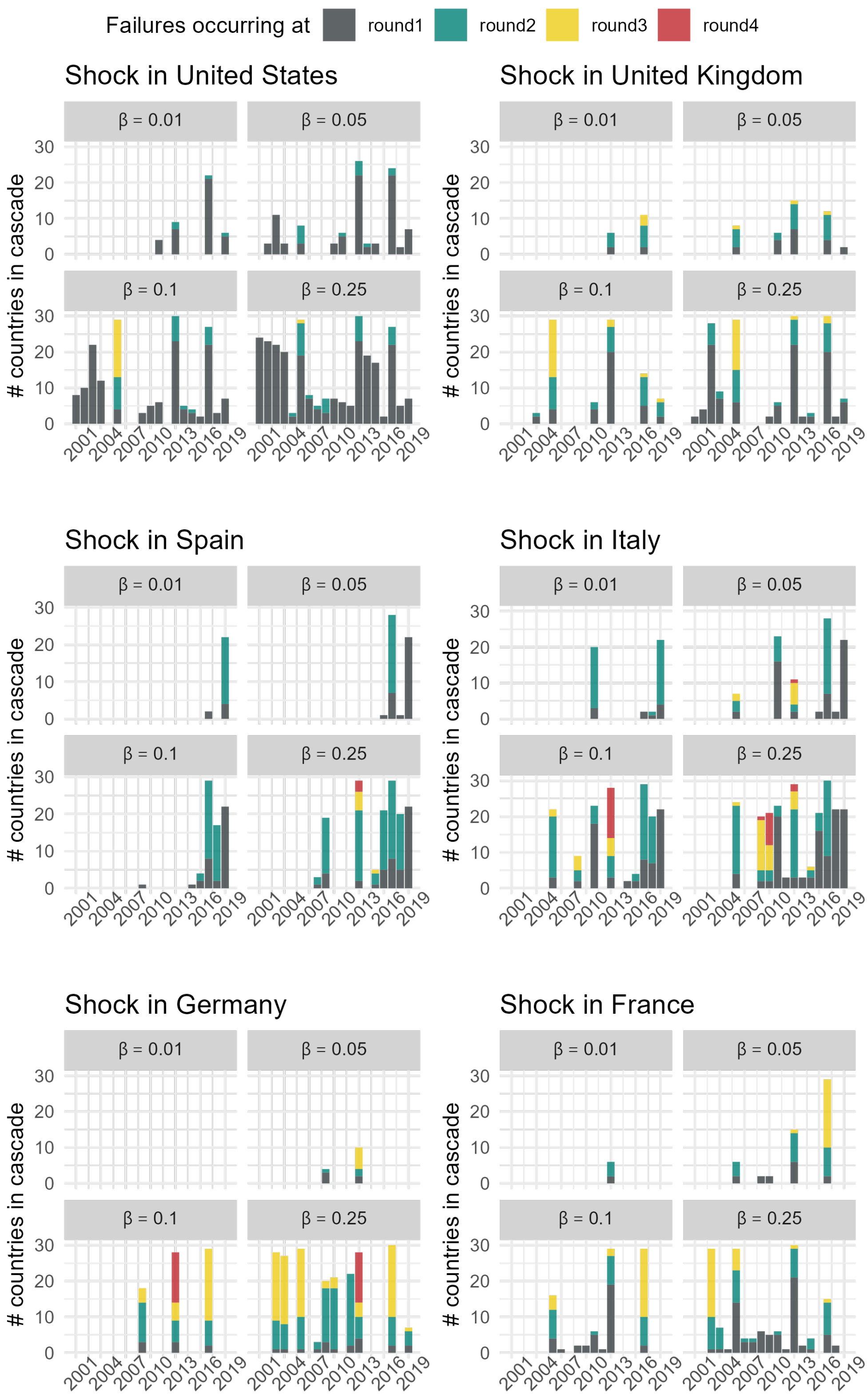

Figure 8: Hierarchy of failures ($\theta = 0.13$).

7 Conclusion

In this work, we analyzed the diffusion of shocks in the international cross-holdings network. Exploratory analyses and the results of the simulations clearly showed that the the network structure of the problem got more and more relevant in recent years. In particular, simulations showed that a financial shock affecting a country can induce a contagion of other countries that ends up in cascade of losses in the real economy. A primary observation from our analysis is the role of the initiating country in shaping the trajectory and intensity of the cascade. When the shock originates from a central player, such as the United States, the subsequent economic fallout is immediate due to the global exposure to its economy. Conversely, when a shock begins in a less central country, it can still reverberate through the international system, causing cascading losses across multiple nations over multiple rounds of contagion. Our results align with theoretical expectations in corroborating that the severity of the shock and the sensitivity to market values play substantial roles in determining the likelihood of a cascade involving many countries. The greater these parameters, the higher the probability of a widespread economic downfall.

While these findings are insightful, they are subject to certain limitations, most notably the availability and extent of our data. Given the small size of our dataset, our estimations could either overstate (by overlooking potential resilience of the network induced by risk diversification of investments in many countries) or understate (as the contagion may actually hit many more countries) the probability of cascade, skewing the perceived impact based on the limited countries included in our analysis. Future research should focus on designing policies and strategies that may prevent or mitigate the impact of such cascades. One promising approach involves adjusting the values of the sensitivity parameter, θ, for specific countries. This could potentially make those economies less susceptible to enduring real losses following a decrease in market capitalization. Another avenue is to study new designs or potential rewirings of the network to enhance its overall resilience. However, such analyses need further theoretical refinements to appropriately understand the factors influencing the parameter θ and the international cross-holding network's structure.

References

Elliott, Matthew, Benjamin Golub, and Matthew O. Jackson (2014). "Financial Networks and Contagion". In: *The American Economic Review* 104.10, pp. 3115–3153. ISSN: 00028282. URL: `http://www.jstor.org/stable/43495315` (visited on 06/30/2023).