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Architectures engender crises: The emergence of power laws in social networks

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HIGHLIGHTS

- A model of network formation that engenders scale-free structures is proposed.
- Nodes are rational lenders or borrowers and links are financial transactions.
- Shocks represent sudden increases or decreases of wealth.
- They propagate on the system yielding small overall effects.
- However, with smaller probability, they impact the entire system.

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ABSTRACT

Recent financial crises posed a number of questions. The most salient were related to the cogency of derivatives and other sophisticated hedging instruments. One claim is that all those instruments rely heavily on the assumption that events in the world are guided by normal distributions while, instead, all the evidence shows that they actually follow fat-tailed power laws. Our conjecture is that it is the very financial architecture that engenders extreme events. Not on purpose but just because of its complexity. That is, the system has an internal connection structure that is able to propagate and enhance initially small disturbances. The final outcome ends up not being correlated with its triggering event. To support this claim, we appeal to the intuition drawn from the behavior of social networks. Most of the interesting cases constitute scale-free structures. In particular, we contend, those that arise from strategic decisions of the agents.

1. Introduction

The structure of the financial system, particularly the network of financial entities and agents as well as the ensuing structure of debts and obligations of all the parties involved in financial transactions are usually jointly deemed as constituting the *architecture* of the system [1].[1] Its main participants are banks, stock exchanges, private investors, governments, etc. The first financial structures, banks, arose as a way of making a more efficient use of resources in

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[1] This characterization combines the institutional and regulatory infrastructure (which for some purists is the only component that should be called "architecture") with the intermediation structure.

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societies in which agents had different time schedules for the use of their money assets. But in the last two centuries the financial architecture became a fundamental component of the economy of modern nations, and more recently of the global economy [2].

From bank deposits to credit default swaps, the financial instruments involve two parties, one lending some resources and the other borrowing them. Interestingly, the last decades showed a continuous growth of the length of the chains of liability, with different forms of insurance against negative events added as a protection for lenders. New and more complicated instruments arose to distribute both potential premiums as well as obligations among even unsuspecting individuals (like pensioners or owners of current accounts). While in many cases a lender of last resort exists (usually governments bailing out institutions in trouble, but also supranational entities), in others cascades of defaulted debts can ensue, hitting all the firms and individuals in the complex chains of obligations [3]. So, for instance, in 2007, defaults on loan mortgages impacted on pension funds, insurance companies, mutual funds, etc. giving raise to the worst economic crisis since the 1930s.

The outbreak of this financial crisis posed a number of puzzling questions. Besides the search for whom to blame, some theoretical questions arose. The most salient were related to the cogency of *derivatives* and other sophisticated hedging instruments. A popular account of why they seem to be flawed appeared in Nassim Nicholas Taleb's "The Black Swan" [4]. There, Taleb claims that all those instruments rely heavily on the assumption that events in the world are guided by normal distributions while, instead, all the evidence shows that they actually follow fat-tailed power laws.

While this hypothesis explains why the financial instruments were not able to cover the title owners from a cascade of negative shocks and their consequences [5], it requires further examination [6]. The underlying mechanism that generates events obeying power laws must be better understood, before engaging in the design of new regulation and prevention policies.

Our conjecture is that it is the very financial architecture that engenders extreme events. Not on purpose but just because of its complexity. That is, the system has an internal connection structure that is able to propagate and enhance initially small disturbances. The final outcome ends up not being correlated with its triggering event.

To support this claim, we appeal to the intuition drawn from the behavior of social networks. Most of the interesting cases constitute *scale-free* structures. In particular, we contend, those that arise from strategic decisions of the agents.

On the other hand, it has been shown that random disturbances in such networks start multiplicative branching processes that generate flows obeying to power laws. This is precisely the core of our argument.

In this paper we will abstract away all the specific details of the financial architecture and see it as a directed graph in which each node is able to borrow from the nodes to which it accesses and lend to the nodes from which it is acceded. Each node is identified with an agent, which is endowed with some amount of a good that can be transferred from and to other agents. By establishing links to other agents she can gain access to the goods held by them, but she has to pay a fee to establish those links. The strategic goal of each rational agent is to maximize the access to the resources held by the others, at the lowest cost possible. Nash equilibria yield the structures from which no individual agent can deviate to increase her benefit.

One of the most influential approaches in the literature has been to conceive the social structure as a network that may arise from random interactions among individuals [7]. Changes in the probability of encounters may lead to drastic changes in the final structure that obtains. In mathematics this is a well-known result, that originates in Erdös and Renyi groundbreaking study on *random graphs* [8]. They showed that if the average number of links established by any agent is slightly increased in a small neighborhood of 1, a complete disconnected graph becomes a completely connected one. Newman et al. [9] have generalized this result for generic probability distributions, showing that intermediate phase transitions exist, at which new components arise in the graph.

We reproduce a similar result, but here it arises from the intentional behavior of rational agents. Unlike in the case of random connections, "mavens", i.e. agents sought for connection, tend to appear. This gives these networks a distinctive scale-free structure.

Consider now a given Nash network. A random shock on a node will follow the already established connections, to fulfill this new request of resources. If this demand surpasses the amount of resources available in the node, it will request, in turn, this difference from its providers. Depending on the stored amounts and the connections, the initial shock might die out quite soon or it might propagate through large portions of the network.

We will prove that if the network has a number of relatively important players and the others are able to pay the fee to attach to them, the network will show all possible behaviors in the propagation of shocks. In particular, the generation, albeit with a rather low probability, of extreme events.

The organization of the paper is as follows. In Section 2 we briefly discuss the financial network of liabilities (the financial *architecture*) and how a crisis may ensue, triggering a chain of losses of wealth. In Section 3 we formalize this in the framework of equilibria networks. In Section 4 we characterize the architecture that may arise when resources are unevenly distributed and the richest nodes act as mavens. We will show that the structure of this network is scale-free. In Section 5, we will analyze the multiplicative branching processes engendered by random shocks and see that the theoretical distribution of perturbations follows a power law.