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Connected we stand: A network perspective on trade and global food security

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ABSTRACT

We analyze the link between virtual water trade, that is, the flow of water embodied in the international trade of agricultural goods, and vulnerability to external shocks from the vantage point of network analysis. While a large body of work has shown that virtual water trade can enhance water saving on a global scale, being especially beneficial to arid countries, there are increasing concerns that openness makes countries more dependent on foreign food suppliers and, in this way, more prone to external shocks. Our evidence reveals that the increased globalization witnessed in the last three decades is not associated with the increased frequency of adverse shocks (in food production). Furthermore, building on recent advances in network analysis that connect the stability of a complex system to its topological features, we find that the world is more interconnected, but not necessarily less stable.

Introduction

This paper investigates whether the globalization of food trade has made the world more vulnerable to shocks and, as a result, whether there is a trade-off between stability and openness. To do so we exploit the insights provided by network analysis: we study the structural features of the web of bilateral trade flows in agricultural goods – and the associated flows of virtual water – to ascertain whether they have evolved in a way that makes the world system more (or less) prone to large disruptions. In our endeavor, we relate to several streams of the existing literature, and interweave them to provide novel and original insights on the relationship between international trade and food security.

The idea of measuring the water ‘embodied’ in goods, and ‘virtually’ traded from one country to another when goods are sold across borders, has been introduced by Allan (1993). In his seminal study, Allan describes virtual water (VW) trade as a market-mediated mechanism that enables water-scarce regions to cope with water scarcity (and food security) over the past few decades. Subsequently, VW flows among countries engaged in trade have been estimated and widely studied (see, for instance, Hoekstra and Hung, 2002; Oki and Kanae, 2004; Hoekstra and Chapagain, 2008; Roson and Sartori, 2015; or Antonelli and Sartori, 2015 for a recent review of the literature).

In the last decade, a number of studies have applied complex network analysis to study the features of VW trade as a global network. This has led to the unveiling of the main topological characteristics of the VW network (Konar et al., 2011; Tamea et al., 2013), highlighting clues of small-world behavior (Shutters and Muneepeerakul, 2012), the occurrence of hubs and rich-club effects (Suweis et al., 2011), and the existence of a community structure (D’Odorico et al., 2012). In Carr et al. (2012), Dalin et al. (2012), and D’Odorico et al. (2012), the temporal evolution of the virtual water network is also analyzed, showing the progressive intensification of VW exchanges and the geography of these variations.

We contribute to this literature by linking the topological features of the global network of VW trade to the resilience of the world system to shocks. In fact, the relationship between network topology and shock propagation has received considerable attention in the last few years, especially since the recent financial crisis has forcefully highlighted the importance of the issue. A series of recent contributions by Acemoglu et al. (2012, 2013, 2015) examine the interplay between idiosyncratic shocks to individual actors in a network and the probability of large cascade effects that could threaten the stability of the system. They show that the propagation of shocks depends on the presence of relatively few dominant sectors. This feature, captured by the presence of heavy (or fat)

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tails in the distributions of some key network indicators, imply that shocks hitting central players will quickly propagate to the rest of the economy, with the complex web of linkages magnifying (rather than dampening) their effect.

Our analysis starts by looking at the distribution and frequency of large shocks in agricultural output over the last three decades, in order to see whether, due to climate change, population growth or other global trends, these shocks have become more common over time. Second, since the structural features of the international trade network connecting countries plays an important role in the transmission of shocks (Acemoglu et al., 2012), we study both the topology and the evolution of the network of trade in agricultural goods (translated into VW flows). We find no evidence of an increased frequency of adverse shocks in food production; moreover, while the globalization of food trade has made the VW network more interconnected over time, its structural characteristics have not evolved in a way that enhance systemic fragility.

Our conclusions therefore contribute, from a novel perspective, to the debate on the relationship between food sovereignty, food security, and trade openness (Montalbano, 2011; Burnett and Murphy, 2014), that is characterized by conflicting views. For instance, Headey (2011) suggests that trade integration may increase a country's exposition to external disturbances, and this is especially true in the case of small countries. However, Paarlberg (2000) argues that transitory food insecurity in poor countries are not induced by changing conditions in international grain markets, rather by internal conflicts and natural disasters, as the reliance of these countries on grain imports is usually low. Furthermore, Allouche (2011) points out that, when water and land resources are scarce, food imports represent the main channel though which countries fulfill their food needs, so that global trade enhances food and water security. For instance, Tanaka and Hosoe (2011) find that protection of the domestic rice market harms, rather than ensures, Japan's national food security. Matthews (2014) claims that an open and predictable trading system plays an essential role in promoting global food security by making the system more efficient and more responsive to shocks. Similar conclusions are reached also by Huang et al. (2011) and Rutten et al. (2013). The former argue that international trade plays an important role in compensating climate-induced changes in productivity; the latter investigate the effects of trade policy responses to a negative supply shock (in the wheat market) and claim that liberalizing trade contributes to food security.

To the best of our knowledge, ours is the first study that applies network analysis and investigates the structural features of VW trade to address the potential trade-off between trade openness and food security. The paper is structured as follows: the next section describes the data used and defines the basic network measures employed in the analysis; Section 'Empirical analysis' illustrates the results of the empirical investigation, while the final section discusses the policy implications and draws some concluding remarks.

Data and methodology

Virtual water and virtual water trade

The VW content of (agricultural) goods is the volume of water that is used to produce them. It depends on several aspects, such as the place and time of production, the technology used and water use efficiency. VW trade refers to the exchange of virtual water implied by international trade, with most authors focusing on agricultural goods, as we also do in this paper.

When a good is exported (imported), its VW content is implicitly exported (imported) as well. Any trade flow can be translated in its VW equivalent by using country-specific measures of the VW content of each product. In this framework, the concept of VW becomes a useful indicator for the study of virtual water exchanges underlying food trade and represents a way to link international trade and water resources. A VW flow is obtained by multiplying the estimated (country-specific) VW content by the volume of trade in agricultural goods registered. Food production and international trade data for a total of 309 crops and animal products for the period 1986–2010 are obtained from the FAOSTAT database, while Mekonnen and Hoekstra (2011) provide estimates of the country-specific VW content of various goods.[1] The total number of countries considered is 253; since the number of active countries varies in time due to geo-political changes (e.g. they are 208 in 1986 and 211 in 2010), inactive countries in a given year were simply removed from the analysis. For each single year, the global matrix of aggregate VW trade is obtained by summing the flows relative to 309 individual crops for which we have information.

Network analysis: basic concepts

The global VW trade system is populated by N nodes (countries), connected by links that represent VW flows. The network is represented by a square matrix W_N (dimensions $N \times N$), where exporters are on rows and importers on columns. Each cell w_{ij} captures the VW flow from country i to country j, with $w_{ii} = 0$. The sum over row i is the total amount of VW exports of country i, while the sum over column j is the total amount of VW imports of country j. The international VW trade gives rise to a weighted and directed network, in which the link direction goes from the exporting to the importing country, and the link of each weight is given by the volume of virtual water flowing between any country pair. From this directed and weighted network one can derive a binary (unweighted) version by disregarding the information on link weights and simply accounting for the presence/absence of a trade connection. In this case the $N \times N$ matrix representing the network is called an adjacency matrix A_N and its generic element a_{ij} is either one or zero depending on whether countries i ad j are connected or not.

The structural features of a network (its topology) are described through several indexes. One of the first ways to characterize a network is to count its players (nodes) and links, and to look at its density, given by the number of active links over their total possible number (if all nodes were connected with every other node).

Node *degree* (k_i), which measures the number of contacts maintained by each node, here translated as the number of trade partners of a country, is defined as $k_i = \sum_j a_{ij}$, where a_{ij} is the element of the binary adjacency matrix A_N. In the case of directed networks, the *indegree* counts the number of edges directed to a certain node, while the *outdegree* represents the number of outgoing links. Applied to the VW trade network, the former is the number of import flows, while the latter counts the number of destinations served.

The weighted counterpart to degree is given by node *strength* (s_i), i.e. is the sum of all the link weights w_{ij} of each node (representing the total VW imports or exports), where $s_i^{in} = \sum_j w_{ji}$ is the indegree (import) strength, while $s_i^{out} = \sum_j w_{ij}$ is the outdegree (export) strength. In the case of VW network, link weights are virtual water flows.

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[1] For a detailed description of the way in which the VW content of the trade flows was computed, we refer to Carr et al. (2012, 2013) and Tamea et al. (2014). We owe a debt of gratitude to these authors, who shared the data on virtual water trade flows. Appendix B reports the list of countries and FAO products considered in computing the virtual water flows. Dalin et al. (2012) and Konar et al. (2011) use a different method, namely the H08 global hydrological model, to determine the virtual water content of different goods.