World trade networks and supply chains: structure, dynamics and fragility

Postdoc proposal

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The complexity of supplying our societies with raw materials or processed products coming from various parts of the world becomes evident in the face of shortages. The covid19 also emphasized this fundamental aspect by highlighting the problems posed by the transport of goods, the number of intermediaries and, more generally, the intricate nature of the manufacture of many products involving many components or ingredients. In particular, we have all understood the extreme fragility of these chains, as they rely on key players and bottlenecks: when the giant container ship "Ever-Given" blocked the Suez Canal in March 2021 [1], world trade was severely impacted and the loss was estimated to about 400 million dollars per hour !

In this research proposal, we will focus on some trade network and more generally on the structure of 'supply chains'. A starting point will be the study of trade networks which concern basic constituents of our nutrition such as wheat, rice, meat, etc. A simplified representation of international exchanges is a network where nodes are countries and directed weighted edges represent export of a given food type. Import-export of these fundamental products are crucial for our societies and have gone through several crises that affected food security in the world. For example, in 2007 and 2010, the conjunction of unfavorable environmental conditions (drought, forest fires) and an increase in demand for agricultural products led to a spectacular surge in food prices, a symptom of food shortage [2]. The mechanism is quite simple: to protect their populations, some countries have decided to reduce or ban exports of certain products, and dependent countries have started to panic. Thanks to this type of mechanism, these food supply shocks are increasing worldwide and propagate from a location to another one [3]. The consequences of these crises can be very significant, with episodes of social unrest and an increase in food insecure populations around the world. With the increase of the world population, the limited amount of resources on our planet and global warming, we can unfortunately expect an increase in the frequency of food crises and price spikes, which were shown to be correlated with social unrest and violent protests (as seen in Africa, in 2008 or in the Middle East in 2011 during big spikes in food prices [4]).

A fundamental problem for these networks is their stability and resilience when there is an important production loss (due to strikes, wars, or climatic hazards for example) occurring in a major exporting country. Despite the breadth and importance of this topic,

research on the vulnerability of these chains to serious disturbances is in its infancy. In situations where supply chains are functioning normally, they are highly optimized to maximize the flow of resources through the system. This optimization is done naturally to the detriment of redundancy and generally imposes low redundancy. With this efficiency comes limited robustness, however, and a failure in one part of a network could propagate through the complex network. The COVID-19 pandemic has exposed a number of vulnerabilities in supply chains and provided the opportunity to study how they operate (particularly in the food sector) under conditions of crisis, allowing identify vulnerabilities and bottlenecks, and brainstorm options to strengthen the whole system. Thus, we have seen that if supermarkets have reduced the diversity of their suppliers for efficiency gains, this leads to fragility vis-à-vis major shocks such as COVID19. So, when these few key suppliers found themselves unable to meet their order book for reasons of workforce health security, or for lack of manpower due to travel restrictions, the supply in supermarkets was severely impacted. In addition to production problems, the transport system itself has been affected and more able to move products due to a lack of drivers or workers responsible for maintaining the infrastructure. Beyond COVID19, climate change, through extreme weather conditions, has and will in the future have a huge impact on the production and availability of food affecting the supply.

The goal of this project is thus to understand the robustness of supply chains in general and of the food network in particular. It will be crucial to identify its weaknesses and eventually to propose strategies for increasing its robustness to shocks. In order to organize this analysis, we propose the following research tasks:

1. Despite the incorrect name, "supply chains" are not simple linear objects but rather complex networks. The first step will be to collect data for these objects and to analyze their structure. For this empirical task, we will have to process data and analyze it with the tools developed in network science [5] and go beyond previous analysis of supply chains [6]. This analysis will enable us to characterize these large structures such as the presence of communities and hubs, but also to identify countries that play particular roles in the global structure. We will also address the important problem of the temporal evolution of these food trade networks which will open the way to the construction of models for the dynamics of these networks. It will also be interesting to explore the interactions between different food types which can be analyzed in the framework of multilayer networks [7].

2. The structure of these networks is however not enough for understanding their robustness and how shocks can propagate worldwide. Indeed, the edges in this network represent in general the import-export relation between countries and is therefore a

dynamical link governed by economic considerations. We thus have to model how a country reacts to a production loss and it will be crucial to interact with economists expert in these systems in order to propose a simplified model of food shock propagation over the global food network. Such a simplified model will have to be based on realistic mechanisms and its predictions will have to be validated by empirical observations.

3. With the simplified model of shock propagation described in (2), we will analyze various production loss scenarios and explore the vulnerabilities of the network. In particular, it will be important to be able to characterize by simple indicators the robustness of countries. Several questions will also be addressed such as how to optimize the robustness of a given country when food shocks are propagating worldwide [8]. Indeed, in situations where supply chains are functioning normally, they are highly optimized to maximize the flow of resources through the system. This optimization generally imposes low redundancy implying usually limited robustness and a failure in one part of a network could easily propagate through the complex network. A detailed understanding of this propagation will enable us to propose mitigation strategies for food shocks propagation that integrate a complex network perspective and not based on optimization considerations only [9]. Our hope is to be able to identify a number of properties that food supply chains should have in order to resist to random or targeted attacks on the network.

Bibliography

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