Measuring Global Value Chain Risks Based on the Absorbing Markov Model with Rewards

Topic: Input-Output Theory and Methodology
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In the intricate landscape of global economics, Global Value Chains (GVCs) have become central to our understanding of international trade and economic symbiosis. GVCs, functioning as complex networks for the production, assembly, and distribution of goods and services, encapsulate more than just economic efficiency; they are pivotal in a landscape teeming with diverse risks. The dense interdependence that typifies these global networks, a consequence of accelerated globalization, makes them especially susceptible to various disruptions. Geopolitical tensions, for instance, can trigger trade restrictions or resource nationalism, leading to supply chain disruptions and inflated costs. Energy scarcity, arising from resource limitations or geopolitical strife, can significantly escalate production expenses and cause delays, reverberating throughout the chain and impacting end-user prices and availability. Moreover, extreme climatic events can have the potential to halt production, devastate infrastructure, or impede logistics. In the realm of GVCs, a disturbance in one part of the chain can rapidly lead to cascading effects, resulting in substantial economic impacts that transcend national boundaries. Therefore, the precise measurement of these risks are crucial in ensuring economic resilience in a world that is deeply interconnected yet marked by uncertainty.

Substantial progress has been made in applying input-output models to quantify risks within GVCs. These studies have adopted innovative approaches, contributing to our understanding of GVC risk dynamics. Some researchers have focused on quantifying the impact of specific shocks, analyzing how changes in volume and production due to events like natural hazards can affect GVCs. Another strand of research has employed techniques such as the hypothetical extraction method, centrality measures, and PageRank theory to identify the most crucial sectors within GVCs. By pinpointing these key sectors, these studies offer a way to understand which parts of the chain are most influential and, therefore, potentially more vulnerable to risks. There have also been attempts to quantify risks based on the frequency with which GVCs intersect with sectors deemed risky. As Inomata and Tanaka (2021) pointed out, a comprehensive risk assessment in GVCs should consider multiple aspects. In this study, we use a similar analogy, where the chances that a factory will be exposed to natural disasters (e.g., hurricanes) more badly because (1) a large amount of the factoryâ€™s production is exposed to hurricanes; (2) the hurricane is more severe; or (3) the hurricanes happen frequently. This study aims to offer a novel method or a more comprehensive framework for quantifying risks in GVCs. Our approach integrates the volume of value-added/energy/emissions passing through the GVCs, the frequency and pathways of these flows, and the inherent risk strength of the country-sectors involved. By combining these dimensions, we seek to provide a more nuanced understanding of the multifaceted nature of risks in GVCs.

This study designed an Absorbing Markov Model with Rewards to trace the risks in GVCs. It employs the input-output table and integrates it with the absorbing Markov process to elucidate the flows within GVCs. The Markov process offers a sequential representation of production from a probabilistic perspective, enabling us to illuminate how production is organized step by step and capture how different countries and sectors are interconnected in production chains. To quantify the transmission of risks within these chains, the study utilizes a Markov Reward Process. In this method, risks are incorporated into the GVCs by assigning a â€œrisk indexâ€• to each country-sector (or to each country-sector- country-sector pair), which can be understood as â€œrewardsâ€• related to each step of move in the supply chain. It also considers a discount rate to describe how risks penetrate/accumulate along the chains. This approach provides a method of

quantifying how risks accompany the flow of goods and services, considering both the intensity and the propagation of risk factors. We apply this model to analyse risks from various starting states (the origin of the chains) or absorbing states (the final products of the chains), between specific starting-absorbing states bilaterally, and through complete pathways from staring state to absorbing state, passing through intermediate risky nodes. This general method makes it applicable to a wide range of aspectsâ€”whether analyzing the flow of value-added, energy, emissions, or other factors and how they pass through different key sectors (assuming the risk index to be identical), or analysing the multi-perspective risks, e.g., climate change risks, natural resources scarcity risks, geo-political risks, socio-economical risks, and etc. Thus, this study could offer both theoretical and practical insights into the realm of global supply chains.