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The Macroeconomic Significance of Disequilibrium

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Abstract

This paper establishes that the contribution of granular shocks to aggregate volatility depends on whether the economy exhibits disequilibrium dynamics in response to the shocks. We characterize a system of buyer-seller relations between firms wherein productivity shocks arrive before the economy reaches the equilibrium pertaining to the last round of shocks. We show that within such a system, the aggregate volatility generated by granular shocks is sizeably smaller than that of an economy which promptly jumps from one equilibrium to another. This difference between equilibrium and disequilibrium aggregate volatility arises from the fact that within the disequilibrium setting subsequent rounds of shocks 'average' each other in a manner reminiscent of the Central Limit Theorem. The extent of such inter-temporal averaging of shocks depends on the rate at which the economy converges to equilibrium. Factors that determine the rate of convergence to equilibrium, like the stickiness of prices and Eigenvalues of the production network, therefore play an important role in determining aggregate volatility. We calibrate the model to a large dataset of buyer-seller relations between firms in the US. Our empirical estimates suggest that disequilibrium aggregate volatility lies somewhere between a fifth and a third of its equilibrium counterpart. This means that when disequilibrium dynamics are at play, granular shocks may not generate much of the observed aggregate volatility even with the production network acting as an amplification mechanism.

Endogenous formation of production networks with imperfect information

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Abstract

We provide a model of the formation of production networks with imperfect in- formation. We consider firms that sequentially explore their local network in search of productivity enhancing technologies. We show that this exploration process generates a Markov process over production networks that converges to equilibrium networks whose structure is determined by the search radius of firms, which we use as a measure of innovativeness. In this setting, we investigate how the structure of equilibrium networks vary with information diffusion and, conversely, how the structure of production networks influence the diffusion of innovations. On the one hand, our model predicts that with increasing information diffusion, production networks become more connected and that their degree distribution shifts to the right. On the second hand, our model provides micro-foundations for the analy- sis of innovation diffusion as a percolation process. We provide a characterisation of a percolation threshold in terms of the spectral radius, show that technological adoption rates will be suboptimal in general, and that the capacity of an economy to adopt innovations decreases with the percolation threshold. Overall, our model replicates a number of stylized facts of the empirical literature on the diffusion of in- novation and provides new testable implications linking the topology of production networks with innovativeness.

Reconstructing large-scale production network

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Abstract

This paper develops an algorithm to reconstruct large weighted firm-to-firm networks using information about the size of the firms and sectoral input-output flows. Our algorithm is based on a four-step procedure. We first generate a matrix of probabilities of connections between all firms in the economy using an augmented gravity model embedded in a logistic function that takes firm size as mass. The model is parameterized to allow for the probability of a link between two firms to depend not only on their sizes but also on flows across the sectors to which they belong. We then use a Bernoulli draw to construct a directed but unweighted random graph from the probability distribution generated by the logistic-gravity function. We make the graph aperiodic by adding self-loops and irreducible by adding links between Strongly Connected Components while limiting distortions to sectoral flows. We convert the unweighted network to a weighted network by solving a convex quadratic programming problem that minimizes the Euclidean norm of the weights. The solution preserves the observed firm sizes and sectoral flows within reasonable bounds, while limiting the strength of the self-loops. Computationally, the algorithm is O(N2) in the worst case, but it can be evaluated in O(N) via sector-wise binning of firm sizes, albeit with an approximation error. We implement the algorithm to reconstruct the full US production network with more than 5 million firms and 100 million buyer-seller connections. The reconstructed network exhibits topological properties consistent with small samples of the real US buyer-seller networks, including fat-tails in degree distribution, mild clustering, and near-zero reciprocity. We provide open-source code of the algorithm to enable researchers to reconstruct large-scale granular production networks from publicly available data.

Bottom-up climate impact assessment

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Abstract

The increasing frequency and severity of extreme weather events due to climate change pose significant risks to the global economy. The resulting losses are transmitted and amplified through supply chains. While existing research primarily examines how climate shocks propagate over a fixed economic structure, this study explores how such shocks influence the evolution of production networks. We construct global synthetic firm-level production networks by following Bhattathiripad and Veetil (forthcoming) and simulate extreme weather events at a plant-level resolution, allowing the network to adapt dynamically to such disruptions. Preliminary findings reveal that output continues to decline even after direct losses stabilize, highlighting the role of propagation dynamics and feedback loops. Moreover, risk assessments based on average losses underestimate extreme scenarios. This study contributes to the understanding of supply chain adaptation to climate shocks and proposes a bottom-up metric for evaluating the global economic impact of extreme weather disruptions.

Mapping the Global Submarine Cable Network: New Data on Topology, Capacity, and Vulnerability

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Abstract

We build a new global dataset on submarine cable topology, redundancy, and capacity for 2010–2025. Capacity has risen exponentially while the network's geography has remained mostly unchanged. Redundancy and capacity are still uneven and percolation analysis reveals persistent fragility across much of the world. Centrality and inter centrality measures indicate that a small cluster of hubs in the MENA–South Asia corridor increasingly anchors global connectivity, with major implications for Africa, Europe, and the Middle East/South Asia, whereas the Americas and most of Asia remain largely insulated. Using seafloor topology, we quantify exposure to sabotage and show vulnerability correlates with network centrality.

Communities in world input-output network: Robustness and rankings

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Abstract

We introduce a method for assessing the robustness of community detection and apply it to a world input-output network (WION) to obtain economically plausible results. This method enabled us to rank communities in the WION in terms of their robustness and stability. The algorithmic assignment variability index proposed in this study is shown to have predictive power in terms of forthcoming community rearrangement. We also provide several new approaches for identifying key economic communities. These approaches are based on the application of several centrality measures to a synthetic network in which nodes represent WION communities. Using these methods, we show that in 2000–2014, United States and Japan-centered communities demonstrated decreasing trends, while the importance of the China-centered community predominantly increased. A notable feature of the Germany-centered community rank evolution is that its influence grew only as a result of the inclusion of the Netherlands and Belgium in 2013.

Industry Aware Firm Level Network Reconstruction

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Abstract

Reconstructing firm-level production networks is essential for studying economic interdependencies and systemic risk, yet such data are rarely available. We develop an industry-aware reconstruction framework that combines firm-level strength data with aggregate input–output (IO) information. First, we extend the density-corrected gravity model by introducing an IO-based bias term that increases the likelihood of links between firms in industries with strong observed inter-sectoral flows. Second, we assign edge weights using iterative proportional fitting to jointly preserve firm-level in/out strengths and IO sectoral totals. We compare the resulting ensemble to the CReM-B model from Parisi et al. [2020] and find that our approach better preserves both firm-level and input–output constraints under realistic sparsity levels. The framework is tested on the 2021 Hungarian VAT-based production network to evaluate structural properties, consistency with IO aggregates, and implications for downstream systemic-risk analyses such is Diem et al. [2022].

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Climate Policy and Trade Restrictions in a Production Network Context: Evidence from a CGE Model for Russia

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Abstract

This research examines how climate policy and trade restrictions propagate through production networks in the Russian economy. Using a Computable General Equilibrium (CGE) model with detailed inter-industry linkages, it analyses the introduction of a domestic emissions trading system (ETS) under conditions of quantitative export constraints and worsening terms of trade. The model extends Burova et al. (2023) by incorporating an auction-based mechanism for export quota allocation, capturing both price and quantity channels of trade adjustment within a networked production structure.

The simulation framework covers six scenarios aligned with NGFS Phase III global climate pathways (NDC, Below 2 °C, Net Zero 2050), each modelled with and without a domestic ETS. These scenarios jointly trace global-to-domestic transmission of shocks through export prices, quantitative restrictions, and carbon costs.

Results show that in adverse external environments—characterised by falling prices for carbon-intensive exports—the binding effect of quantitative quotas weakens, as equilibrium export volumes fall below imposed limits. The opposite holds when world prices for carbon-rich fuels remain stable or rise: in such cases, the domestic cost of quantitative restrictions increases sharply, amplifying welfare losses.

Network analysis within the CGE framework reveals asymmetric propagation: upstream sectors (oil extraction, refining, pipeline transport) contract sharply, while downstream and demand-driven industries (chemicals, machinery, food processing) gain relative weight through input substitution and domestic reallocation.

At the macro level, an ambitious 70 % cut in CO_2 emissions relative to 2016, combined with declining export prices, reduces GDP by about 11 % by 2040, whereas a moderate policy (36 % reduction) results in only a 4.7 % decline, of which 0.3 percentage points stem from the ETS itself. Recognition of Russia's ETS in international markets slightly mitigates these effects through higher effective export prices.

The findings underscore that the structure of production and trade networks critically shapes the transmission and magnitude of climate-policy shocks. Integrating carbon pricing into export-oriented supply chains without access to global green technologies amplifies systemic effects along the network. A feasible transition path therefore requires moderate, internationally coordinated climate policy, combined with investment in low-carbon, export-oriented industries, to sustain both emission reduction and network resilience.

Keywords: Production networks, Russia, climate policy, CGE, NGFS scenarios, export restrictions, emissions trading

JEL: C68, F13, Q52, Q54, Q58

A Control-Theoretic Framework for Supply Chain Resilience: Applying Disturbance Decoupling to Prevent Cascading Disruptions

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Abstract

Modern supply chains are complex networked systems, comprising interdependent subsystems such as suppliers, manufacturers, and distributors. This structure can be naturally modeled as a multi-agent system. However, their interconnectedness also creates vulnerability; disruptions originating from internal dependencies or external shocks (e.g., geopolitical events or natural disasters) can propagate as cascading failures, severely disrupting vital industries. Therefore, developing methodologies to protect critical segments of the supply chain from these propagating disruptions is a concern for ensuring economic resilience.

This work explores the applicability of the Disturbance Decoupling Problem (DDP), a foundational concept in geometric control theory, to enhance the resilience of supply chain networks. In a multi-agent system framework, DDP provides a formal methodology for designing state or output feedback control laws that protect a specified subset of nodes such as critical manufacturing or distribution hubs from disturbances affecting other parts of the network. By framing the supply chain under this control-theoretic perspective, we investigate the conditions under which such a decoupling is achievable.

Critical Minerals in Global Production Networks:
A Perspective on Goods–Services Linkages

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Abstract

Critical minerals such as lithium, nickel, copper, and cobalt form the backbone of the global energy transition, yet their supply chains exhibit severe structural imbalances. While mining is geographically distributed, midstream processing for most minerals is highly concentrated, creating systemic vulnerabilities that amplify the impact of disruptions. Existing assessments of mineral security focus overwhelmingly on physical production, overlooking the equally critical role of services that govern how minerals move through fragmented global production networks. Using constructed indicators, the paper compares structural vulnerabilities across minerals and selected economies. The results demonstrate that resilience is overwhelmingly shaped by structural positioning: countries with significant mining or processing dominance display higher baseline resilience, while those relying solely on strong services ecosystems (notably India and, to a lesser extent, the United States) remain constrained by limited upstream and midstream capacity. By integrating service performance with mining and processing structure, this study demonstrates that resilience in critical mineral supply chains emerges from the interaction of physical concentration and service-enabled connectivity. The findings provide a policy-relevant framework for identifying where countries, especially India, can realistically strengthen their strategic position through targeted investments in processing capacity, logistics infrastructure, and digital coordination systems, rather than relying solely on downstream manufacturing or services competitiveness.

When Is Degree Enough? Bounds on Degree-Eigenvector Misalignment in Assortative Structured Networks

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Abstract

A tight alignment between the degree vector and the leading eigenvector arises naturally in networks with neutral degree mixing and the absence of local structures. Many real-world networks, however, violate both conditions. We derive bounds on the divergence between the degree vector and the eigenvector in networks with degree assortativity and local mesoscopic structures such as communities, core-peripheries, and cycles. Our approach is constructive. We design sufficiently general degree-preserving rewiring algorithms that start from a neutral benchmark and monotonically increase assortativity and the strength of local structures, with each step inducing a perturbation of the adjacency matrix. Using the Stewart--Sun Perturbation Bound, together with explicit spectral-norm control of the rewiring steps, we derive upper bounds on the angle between the eigenvector and the degree vector for modest levels of assortativity and local structures. Our analytical bounds delineate regions of `spectral safety' in which a node's degree can be used as a reliable measure of its systemic importance in real-world networks.

The Effects of Tariffs in the Multicountry Network Model

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Abstract

We present a multicountry extension of the network economic model studied in Mandel et al (2019), Mandel, Veetil (2021). Motivated by the recent developments in international trade, we study the introduction of tariffs on intermediate and/or final products imposed by certain countries on other countries. We show that it can lead to non-trivial effects on countries' welfare and international trade. The network spillovers appearing as a result of the tariff shock introduction are analyzed in the series of small stylized examples and in the real-world data. We show that the spillovers affect the dynamics of both nominal and real model variables.

Global Value Chains and Trade

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Abstract

This paper argues that deeper integration into global value chains (GVCs) provides a more effective path to job creation and economic resilience than protectionist approaches. By leveraging its comparative advantage in labour-intensive activities, India can capitalize on global manufacturing shifts through backward-linked GVC participation. We highlight the need to transition from traditional industrial policy (IP) approaches to those aligned with GVCs. Conventional IP often results in inefficiencies, protectionist tendencies, and resource misallocation. In contrast, a GVC-oriented framework prioritizes global specialization, unrestricted access to inputs, export-driven growth, and partnerships with multinational enterprises (MNEs). By embedding local firms into GVCs, countries can harness comparative advantages, achieve strategic value chain upgrading, and enhance global competitiveness. India's mobile phone manufacturing sector illustrates this shift. Policies like the Production Linked Incentive (PLI) scheme replaced import-substitution measures, focusing on exports and global integration. The subsequent steady growth in production, exports and jobs highlights the advantages of modern, GVC-aligned industrial policies for sustainable development and resilience.

Omori Law after Large-scale Destruction of Production Network

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Abstract

After the two giant earthquakes, Kobe 1995 and East Japan 2011, a large-scale destruction took place on the supplier-customer network. These primary and exogenous shocks were propagated on the production network, which caused a secondary effect resulting in chained bankruptcies. By employing data of bankruptcies occurring in a neighbor to the primarily damaged firms or regional economy, we show that the number of neighboring failures obeys a kind of Omori law, a power-law relaxation. This finding implies that the recovery from such a huge shock on production network is much more sluggish than one can naively expect.