Atif Rao

Ph.D. Candidate in Agricultural Economics | Fulbright Scholar
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September 14, 2026

Professors Emily Breza, Arun Chandrasekhar, and Davide Viviano
Workshop Organizers
NBER Workshop on Development Economics and Networks for Early-Career Researchers

Re: Application to the NBER Workshop on Development Economics and Networks

Dear Professors Breza, Chandrasekhar, and Viviano,

I am writing to apply to the NBER Workshop on Development Economics and Networks for Early-Career Researchers. I am a dissertation-writing Ph.D. candidate in Agricultural Economics at Kansas State University and a Fulbright Scholar. My dissertation defense is scheduled for September 17, 2026, with degree completion expected in December 2026. My research lies at the intersection of development and agricultural economics, international trade, climate risk, and applied econometrics, with particular interest in how economic networks transmit and absorb environmental shocks.

My working paper, *"Correlated Climate Risk in Trade Networks: Supplier Floods and Sourcing Adjustment in Global Rice Markets,"* studies how climate shocks propagate through predetermined international sourcing relationships. I treat an importer's supplier network as a portfolio of climate exposures and examine whether adjustment toward alternative suppliers depends on the covariance of climate risk embedded in that network. The paper connects trade-based climate adaptation to questions of network exposure, supplier substitution, and shock propagation.

The workshop is closely aligned with the direction of my research. I would particularly value feedback on the paper's empirical network design, measurement of correlated supplier exposure, and interpretation of sourcing adjustment following supplier shocks. I would also welcome the opportunity to engage with researchers working on related questions in development economics and empirical networks.

If I am shortlisted, the following faculty member can provide a recommendation:

Professor Nelson Villoria
Department of Agricultural Economics
Kansas State University
Email: nvilloria@ksu.edu

Thank you for considering my application. I would be grateful for the opportunity to participate in the workshop.

Sincerely,
Atif Rao

Atif Rao

Agricultural & Development Economics | **International Trade** | **Climate Risk** | **Economic Networks**

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Education

Kansas State University **Expected Dec 2026**
Ph.D. Candidate in Agricultural Economics – Fulbright Scholar *Manhattan, Kansas, USA*

- Dissertation: *Three Essays on Extreme Weather, Agricultural Markets, and International Trade*.
- Major Professor: **Dr. Andrew Barkley**.
- Dissertation defense scheduled for **September 17, 2026**.

Friedrich Schiller University of Jena **Mar 2015**
M.Sc. Economics *Jena, Germany*

- Thesis: *An Empirical Analysis of the Impact of FDI on Innovation* – distinction in thesis.

Bahauddin Zakariya University **Aug 2010**
Bachelor in Business Administration and Information Technology *Multan, Pakistan*

Research Fields

Development Economics; Economic Networks; International Agricultural Trade; Climate and Environmental Economics; Agricultural and Food Markets; Applied Microeconometrics; Climate Risk and Adaptation.

Graduate Coursework

Ph.D. Coursework – Kansas State University

Econometrics & Methods	AGEC 901 Research Methods in Economics; ECON 830 Econometrics I; ECON 930 Econometrics II; AGEC 936 Quantitative Topics in Agricultural Economics; ECON 735 Mathematical Economics.
Microeconomic Theory	ECON 940 Advanced Microeconomic Theory I; ECON 945 Advanced Microeconomic Theory II.
Macroeconomic Theory	ECON 805 Macroeconomic Theory I; ECON 905 Macroeconomic Theory II.
Agricultural Economics	AGEC 905 Agricultural Demand and Commodity Markets; AGEC 923 Economics of Agricultural Production.
International Trade	ECON 981 International Trade Theory and Policy.
Doctoral Research	AGEC 999 Ph.D. Research (Summer 2024; Spring, Summer, and Fall 2025; Spring and Summer 2026; **current Fall 2026**).

Selected M.Sc. Coursework – Friedrich Schiller University Jena

Advanced Microeconomics; Advanced Macroeconomics; Empirical Methods; Quantitative Economics I; Quantitative Economics III; International Political Economy I: Trade and Development; International Political Economy III: Guided Reading in International Economics; International Economic Law / WTO Law; Fiscal Policy in Open Economies; European Competition Policy; Economics of Innovation; Money and Financial Markets.

Working Papers

- **Rao, Atif**. "Correlated Climate Risk in Trade Networks: Supplier Floods and Sourcing Adjustment in Global Rice Markets."
  Submitted to the NBER Workshop on Development Economics and Networks for Early-Career Researchers.
  Studies how predetermined supplier networks, correlated climate exposure, and sourcing relationships shape adjustment to supplier floods in global rice markets.
- **Rao, Atif** and Nelson Villoria. "Weather Extremes, Production Value, and Export Allocations: Evidence from Corn and Soybeans in the U.S. Midwest."
  Journal of the Agricultural and Applied Economics Association, **Revise and Resubmit; revision submitted**.
- **Rao, Atif** and Nelson Villoria. "The Impact of Flood Disasters on Rice Trade Flows in Southeast Asia."
- **Rao, Atif** and Nelson Villoria. "Floods, Export Policy, and Rice Trade in South Asia: Heterogeneous Responses across Exporters."

Publications

Rao, Atif, Muhammad Ali, and Jason M. Smith (2024). "Foreign Direct Investment and Domestic Innovation: Roles of Absorptive Capacity, Quality of Regulations and Property Rights." *PLOS ONE*, 19(3), e0298913. [Article]

Research Experience

Kansas State University **2022–Present**
Graduate Research Assistant, Agricultural Economics *Manhattan, Kansas, USA*

- Conduct empirical research on **climate shocks, agricultural markets, international trade, economic networks, and climate adaptation**.
- Study how extreme weather and disaster shocks propagate through agricultural production and international sourcing relationships, with particular attention to **supplier dependence, market concentration, substitution, and correlated climate exposure**.
- Apply **structural gravity, PPML, panel fixed effects, shift-share exposure designs, difference-in-differences, event studies, and wild-cluster inference**.
- Construct and analyze large multi-source datasets combining **ITPD-E, EM-DAT, PRISM, CMIP6, USDA NASS, USDA ERS, FAO, and international trade data** using R, Python, and Stata.

Management Systems International (MSI) **Aug 2016–Jan 2017**
Field Researcher – Program Evaluation and Applied Research *Islamabad, Pakistan*

- Supported program evaluation through stakeholder interviews, primary data collection, research instruments, field documentation, and evidence synthesis.
- Used **MAXQDA** for qualitative coding and triangulation of interview and field evidence.

Sustainable Development Policy Institute (SDPI) **Feb 2016–Aug 2016**
Research Associate – Climate and Development Policy *Islamabad, Pakistan*

- Conducted policy-oriented research on **climate change, agriculture, rural livelihoods, public investment, and sustainable development**.
- Analyzed national and provincial budgets to assess climate-related public expenditures, adaptation priorities, and resource-allocation gaps.
- Contributed to research on the **China–Pakistan Economic Corridor (CPEC)**, including infrastructure, energy, development, and environmental-policy implications.

Friedrich Schiller University of Jena **2014–2015**
Research Assistant – Economics *Jena, Germany*

- Supported empirical research through literature reviews, data collection, quantitative analysis, and preparation of tables and figures related to investment, innovation, and economic development.

Selected Research Presentation

Weather Extremes and Agricultural Exports in the Midwest of the United States: Evidence from Corn and Soybeans
Risk and Profit Conference, Kansas State University, Manhattan, Kansas, August 2025.

Teaching and Academic Experience

Northwest Minzu University **Mar 2017–Mar 2022**
Vice Director and Lecturer of Economics *Lanzhou, China*

- Taught **Quantitative Methods in Economics, Financial Economics, International Finance, Global Economic Issues, and Economics and Law**.
- Developed lectures, quantitative exercises, case studies, assessments, and course materials for students with diverse academic backgrounds.
- Co-managed an international academic program with **Utah State University**, supporting curriculum coordination, academic administration, course scheduling, and student advising.

Bahauddin Zakariya University **2015–2016**
Lecturer – Microeconomics *Multan, Pakistan*

- Taught undergraduate and MBA-level microeconomics, including demand, costs, pricing, market structure, and economic decision making.

Empirical Methods and Data

Applied Econometrics	Panel-data models; two-way fixed effects; structural gravity; PPML; shift-share exposure designs; event studies; difference-in-differences; robustness analysis; wild-cluster inference.
Networks & Trade	Predetermined supplier networks; bilateral sourcing relationships; network exposure; supplier concentration; correlated climate risk; supplier substitution; international and domestic trade margins.
Climate Economics	Extreme-temperature measures; precipitation and flood exposure; historical weather data; climate-risk measurement; CMIP6 climate projections and scenario analysis.
Programming	R; Python; Stata; Excel; GitHub; reproducible research workflows.
Data	ITPD-E; EM-DAT; PRISM; CMIP6; CRU; USDA NASS; USDA ERS; FAO; USITC; UNCTAD; WDI; agricultural, climate, disaster, and international trade datasets.

Awards and Honors

- **Fulbright Ph.D. Scholarship**, United States Educational Foundation in Pakistan, 2022–2026.
- **Third Place, AAEA Graduate Case Study Competition**, Agricultural and Applied Economics Association Annual Meeting, Denver, Colorado, 2025.

Leadership and Professional Engagement

Vice President, Fulbright Kansas State Group *2025–Present*
Kansas State University, Manhattan, Kansas, USA

Vice President, International Buddies Group *2024–2025*
Kansas State University, Manhattan, Kansas, USA

President, Pakistan Student Association *2013–2015*
Friedrich Schiller University of Jena, Jena, Germany

International Experience and Languages

International Experience	United States – doctoral research in agricultural economics; Germany – graduate education and economic research; China – university teaching and academic administration; Pakistan – development-policy research, evaluation, and university teaching.
Languages	English (fluent); Urdu/Hindi (native); German (conversational); Arabic (basic); Mandarin (basic).

Research Interests and Motivation for Attending the Workshop

Atif Rao

My research interests are rooted partly in my own experience with agriculture. I grew up in Kot Mithan, a rural area of Pakistan, where my family cultivated a small farm of approximately three to four acres. I remember periods of unusual weather affecting agricultural production and, in turn, our household income, although at the time I did not understand these experiences in terms of climate risk. Those observations later became closely connected to the questions I study as an economist: how environmental shocks affect agricultural markets and how trade and economic networks transmit or absorb those shocks.

My research now lies at the intersection of development economics, international trade, agricultural markets, and climate risk. A common theme across my work is that environmental shocks need not remain local. Their effects can propagate through production systems, trade relationships, and international markets, shaping adjustment far from the location of the original physical shock.

My current working paper, *"Correlated Climate Risk in Trade Networks: Supplier Floods and Sourcing Adjustment in Global Rice Markets,"* brings this research agenda directly into empirical network economics. I treat an importer's sourcing relationships as a network of supplier-specific climate exposures and ask when international sourcing provides effective diversification against supplier shocks. Using bilateral rice trade, EM-DAT flood records, and predetermined historical supplier shares, I examine whether importers redirect purchases across established supplier links when important origins experience floods and whether this adjustment weakens when alternative suppliers face correlated climate risk.

The paper emphasizes a distinction that increasingly motivates my research: network connectivity is not necessarily equivalent to network resilience. An importer may source from several countries and still remain highly exposed if those suppliers are vulnerable to similar environmental shocks. The relevant economic object is therefore not only the number or concentration of supplier links, but also the covariance structure of the risks embedded in those relationships. This perspective connects food-import dependence and climate adaptation with broader questions of substitution, shock propagation, and resilience in economic networks.

Developing this project has raised empirical questions I would like to pursue further: how to identify adjustment through pre-existing links, how to construct exposure measures when a small number of central nodes account for much of the relevant variation, how to conduct inference when shocks are correlated across nodes, and how to distinguish genuine risk diversification from simple expansion in network connections.

The NBER Workshop on Development Economics and Networks is closely aligned with this direction of my research. I would particularly value feedback on the paper's empirical network design, measurement of correlated supplier exposure, and interpretation of sourcing adjustment following supplier shocks. I would also benefit from engaging with researchers studying networks in other development settings and from understanding how the identification and measurement issues in my application relate to the broader frontier of empirical network research.

Looking forward, I plan to develop a broader research agenda on climate shocks and economic networks, with particular attention to agricultural and food markets. I am interested in when trade networks absorb rather than propagate shocks, how dependence on central suppliers constrains adjustment, and how correlated environmental risks alter the value of diversification. The workshop would provide an especially valuable setting to strengthen this agenda as I move from the dissertation toward independent research.

Correlated Climate Risk in Trade Networks: Supplier Floods and Sourcing Adjustment in Global Rice Markets

Atif Rao

Prepared for the NBER Workshop on Development Economics and Networks for Early-Career Researchers, December 5, 2026

Abstract

This paper studies when international sourcing provides effective diversification against climate shocks. Drawing on the portfolio-diversification logic of Markowitz (1952), we treat an importer's rice-sourcing network as a portfolio of supplier-specific flood exposures and ask whether adjustment depends on the covariance of climate risk across alternative suppliers. Using bilateral and constructed domestic rice flows for 1986–2022, EM-DAT flood records, and predetermined supplier shares fixed at their 1986–1990 values, we document three results. First, the global rice network is concentrated and supplier flood risks are positively correlated across major Asian exporters, substantially amplifying exposure for some importers. Second, importers reallocate purchases toward alternative suppliers when historically important rivals flood, although this substitution margin becomes modest under more demanding fixed effects and inference. Third, adjustment is weaker when alternative suppliers carry more correlated climate risk. In the 2011 Thailand flood episode, importers with greater pre-event dependence on Thailand increased purchases from alternative origins, but the total-import-value response was weaker for those whose alternative suppliers had higher flood covariance with Thailand. A complementary specification also shows greater persistence in purchases from flooded core suppliers among historically dependent importers. The results imply that trade-based climate resilience depends not only on the number of suppliers, but on the correlation structure of climate risk across them.

Keywords: trade networks; portfolio diversification; correlated climate risk; supplier substitution; structural gravity; shift-share exposure; climate adaptation

1. Introduction

International trade can insure food-importing economies against localized climate shocks: when one origin is disrupted, importers may redirect purchases toward other suppliers. This adjustment margin is central to work showing that trade openness can mitigate the local consequences of weather shocks (Burgess and Donaldson, 2010; Costinot, Donaldson, and Smith, 2016; Gouel and Laborde, 2021). But having several suppliers does not necessarily imply effective insurance. If those suppliers are exposed to similar climate risks, they may be hit at the same time.

This is the portfolio-diversification logic of Markowitz (1952): risk depends not only on the number and concentration of exposures, but also on their covariance. The same principle appears in financial networks, where correlated exposures weaken diversification (Elliott, Golub, and Jackson, 2014). It is especially relevant for agriculture because climate shocks can be spatially correlated across major producing regions (Tigchelaar, Battisti, Naylor, and Ray, 2018; Mehrabi and Ramankutty, 2019; Gaupp, Hall, Hochrainer-Stigler, and Dadson, 2020), while staple-food exports are concentrated in a small number of origins. Recent work also shows that weather shocks can affect agricultural export dynamics, trade policy, and food-market adjustment (Tembata and Takeuchi, 2018; Amodio et al.,

2024; Nes et al., 2025; Hsiao, Moscona, and Sastry, 2026). Shocks can therefore propagate through trade relationships rather than remain confined to the place where the physical disruption occurs (Puma, Bose, Chon, and Cook, 2015).

This paper asks: *when does an international sourcing network actually diversify climate risk?* We treat an importer's supplier network as a portfolio of correlated climate exposures. The mechanism is substitution across supplier links: if alternative origins remain unaffected, importers can redirect purchases toward them; if alternatives face the same climate risk, that margin is weaker. The relevant measure of resilience is therefore not simply the number of suppliers, but the concentration and covariance structure of shocks across the sourcing network.

This question links trade-based climate adaptation to the economics of networks. A broad literature shows that shock propagation depends on network structure, concentration, and the location of shocked nodes (Acemoglu, Carvalho, Ozdaglar, and Tahbaz-Salehi, 2012; Elliott, Golub, and Jackson, 2014; Barrot and Sauvagnat, 2016; Boehm, Flaaen, and Pandalai-Nayar, 2019; Carvalho, Nirei, Saito, and Tahbaz-Salehi, 2021). In our setting, exporters are the nodes, historical sourcing relationships are the links, and floods are the shocks. Rice provides a useful setting because more than half of the world's population depends on it, international supply is concentrated, and several major exporters are located in monsoon Asia, where flood risks are spatially correlated (FAO, 2023; Li, Rosa, and Gorelick, 2025; IPCC, 2023).

We combine bilateral and constructed domestic rice flows from ITPD-E for 1986–2022 (Borchert et al., 2021; Larch et al., 2025) with annual EM-DAT flood counts. To separate historical network structure from contemporaneous adjustment, each importer's supplier shares are fixed at their 1986–1990 averages; network regressions use 1991–2022 outcomes. We first characterize network concentration and cross-supplier flood covariance, then test whether importers shift purchases toward alternative suppliers when historically important rivals flood, and finally ask whether this substitution is weaker when the alternative portfolio carries more correlated risk.

Three results organize the paper. First, the network is concentrated: the inverse-Herfindahl measure implies about six effective supplier shocks, and Thailand and the United States account for more than half of aggregate predetermined exposure. Flood counts are strongly correlated across several Asian suppliers—Thailand–Vietnam 0.46, Vietnam–India 0.56, and India–Pakistan 0.58—but less so across hydroclimatically distinct origins, including Thailand–United States 0.15 and Thailand–Pakistan 0.03. This covariance raises fixed-share exposure variance by about 65 percent for the Philippines and 40 percent for Côte d'Ivoire relative to an independent-shock benchmark.

Second, importers appear to substitute across supplier links, but the continuous estimate is modest under demanding specifications. Rival exposure raises purchases from an unaffected supplier by 0.042 in the baseline dyadic specification, but the coefficient falls to 0.011 after supplier-year and importer-decade fixed effects and is only marginally significant under a wild-cluster bootstrap ($p \approx 0.06$). We therefore treat this margin as suggestive rather than precisely identified.

Third, and central to the paper, adjustment is weaker when alternative suppliers carry more correlated climate risk. The continuous interaction has the predicted negative sign but is imprecise. A sharper event-based analysis of the 2011 Thailand floods shows that importers with greater pre-event Thai dependence increased purchases from alternative suppliers (pooled DID coefficient about 1.0; wild-bootstrap $p = 0.003$), while the total-import response was substantially weaker when those alternatives had higher flood covariance with Thailand (triple-difference interaction -0.83, $z \approx 5.5$). A complementary saturated specification also shows that more historically dependent

importers purchase relatively more, in value, from a flooded core supplier, consistent with limited short-run substitutability or supplier lock-in.

The contribution is threefold. First, we distinguish *supplier diversification* from *effective risk diversification*: the number of trade links can be a poor measure of resilience when shocks across those links are positively correlated. Second, we study the adjustment margin that gives those links economic value—substitution across historically established suppliers after a climate shock. Third, we connect trade-mediated adaptation to network propagation by showing that a sourcing network can absorb a localized shock when alternative nodes remain available but can transmit exposure when risk is concentrated or correlated. This perspective places climate adaptation inside a standard economic problem of diversification under correlated risk: the same network can look diversified in terms of partner count yet remain fragile because the underlying shocks covary. In this sense, the portfolio covariance of supplier shocks is an economically distinct feature of network resilience.

We remain explicit about scope. Outcomes are trade values, domestic observations in ITPD-E are constructed rather than observed internal shipments, and the continuous leave-one-out design cannot absorb importer-year fixed effects without changing the estimand. The Thailand event also provides a sharper test rather than a clean natural experiment because other developments in the Thai rice market coincide with the flood episode. The results therefore speak to sourcing adjustment and import-value exposure, not quantities, prices, food availability, or welfare.

2. Data and the Predetermined Rice Trade Network

2.1 Trade data, flood shocks, and predetermined shares

We use ITPD-E Release 3 for 1986–2022 (Borchert et al., 2021; Larch et al., 2025), with rice defined as industry 2. International observations have exporter $i \neq j$; domestic observations have $i = j$ and are constructed as gross production value minus total exports rather than observed internal shipments. The importance of domestic flows for structural-gravity estimation is emphasized by Yotov (2022). Because the ITPD-E domestic observations are constructed rather than observed internal shipments, we use them as a domestic-market benchmark. All outcomes are trade values, and PPML retains zero bilateral flows (Santos Silva and Tenreyro, 2006).

Flood exposure comes from EM-DAT and is measured as the annual number of recorded flood events in each exporter; exporter-years with no recorded event are set to zero. The measure captures frequency rather than severity or spatial overlap with rice-producing areas. We therefore interpret a flood count as a common exporter-level shock proxy rather than a direct measure of the physical damage to rice production. This distinction is important when reading both the gravity coefficients and the supplier-network responses.

For the network analysis, let w^0_{mj} denote importer m's average share of rice imports from supplier j during 1986–1990. We hold these shares fixed and use 1991–2022 outcomes. The network sample contains 87,360 importer–supplier–year observations, 2,730 active links, 166 importers, and 40 major suppliers. Fixed shares define the pre-existing sourcing network and prevent contemporaneous sourcing changes from mechanically reweighting exposure. Economically, exposure is therefore driven by a historical sourcing pattern interacted with subsequent exporter flood realizations, rather than by contemporaneous portfolio adjustment. The baseline is not genuinely pre-sample, but nearby windows are stable: 1986–1990 and 1986–1995 supplier shares correlate at 0.86. A genuinely pre-1986 network would require an alternative source such as FAO or Comtrade. The fixed shares should

therefore be read as predetermined within the network analysis, not as a fully pre-sample instrument for the entire 1986–2022 period.

2.2 Concentration and correlated supplier risk

The network is concentrated. In the full descriptive network, India accounts for about 23 percent of world rice exports, Thailand 21 percent, and the United States 12 percent; Thailand serves 201 of 207 importers. The restricted network-regression sample contains 166 importers and 40 major suppliers. For the exposure design, Thailand accounts for 30.6 percent of aggregate predetermined exposure and the United States 22.0 percent. The inverse-Herfindahl measure implies 6.2 effective supplier shocks. Thus a large importer–supplier panel does not translate into many independent sources of identifying variation, which is why we treat precision from the shift-share design cautiously and use exposure-appropriate inference (Adão, Kolesár, and Morales, 2019; Borusyak, Hull, and Jaravel, 2022).

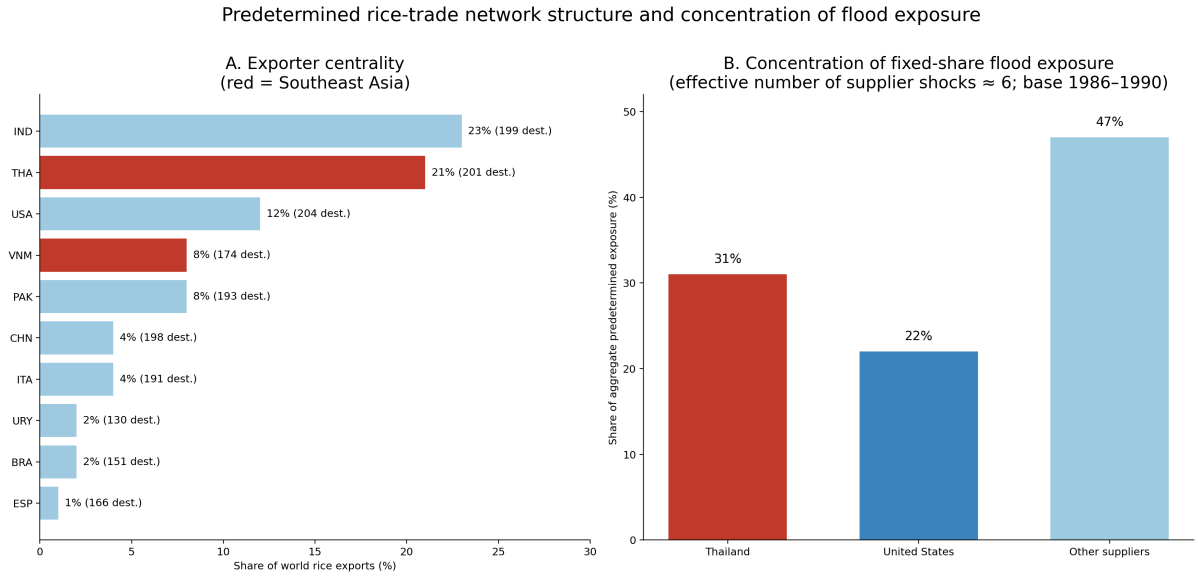


Figure 1. Predetermined rice-trade network and concentration of flood exposure. *Panel A.* Exporter centrality in the global rice network: India accounts for about 23 percent of world rice exports, Thailand 21 percent, and the United States 12 percent. *Panel B.* Import-weighted contributions to fixed-share flood exposure using 1986–1990 supplier shares: Thailand accounts for 30.6 percent and the United States 22.0 percent. The effective number of supplier shocks is 6.2.

Supplier shocks are also correlated. Flood correlations are high across several monsoon-Asia exporters—Thailand–Vietnam 0.46, Vietnam–India 0.56, India–Pakistan 0.58, and China–India 0.62—and much smaller across several extra-regional origins, including Thailand–United States 0.15 and Thailand–Pakistan 0.03. Hence supplier links are not equivalent from a risk diversification perspective.

For importer m, fixed-share flood exposure is

$$FloodExposure_{mt} = \sum_{j} w^{0}_{mj} Flood_{jt}. \tag{1}$$

Following Markowitz (1952), its variance decomposes into own-supplier variance and cross-supplier

covariance:

$$Var(FloodExposure_{mt}) = \sum_{j}(w^0_{mj})^2 Var(Flood_{jt}) + \sum_{j\neq\ell} w^0_{mj} w^0_{m\ell} Cov(Flood_{jt}, Flood_{\ell t}). \tag{2}$$

The two terms distinguish own-supplier risk from risk created by cross-supplier comovement. We define the *exposure-amplification factor* as total variance divided by the first, independent-shock component. Values above one indicate that cross-supplier covariance raises exposure. The factor is about 1.6–1.9 for Qatar, Saudi Arabia, the Philippines, Sri Lanka, and Nepal, and about 1.4 for Côte d'Ivoire. Importers concentrated on one hub can have factors near or below one because they carry little cross-supplier covariance, not because they are well diversified. The amplification factor should therefore be read jointly with concentration: a highly concentrated importer can have little covariance simply because it relies on one dominant origin, whereas a diversified-looking importer can face high amplification when its suppliers share common climate risk. This distinction motivates the separate HHI and covariance interactions used below.

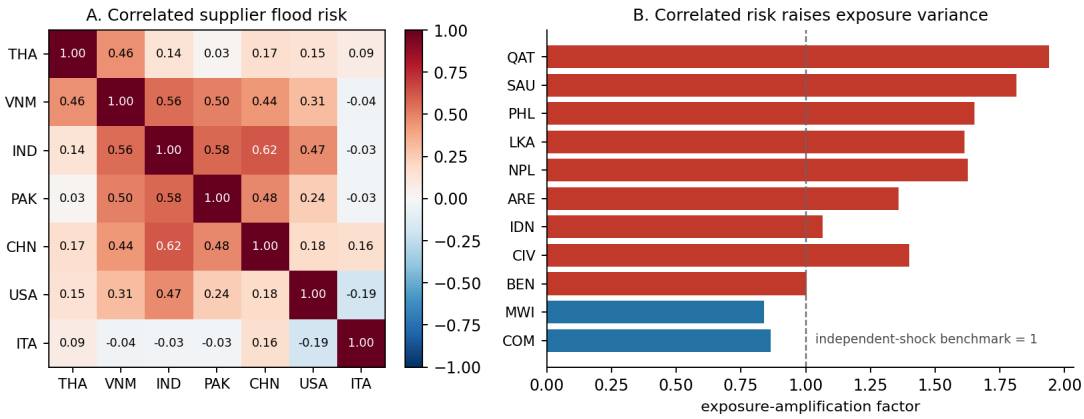


Figure 2. Correlated supplier flood risk and exposure amplification. *Panel A.* Correlations of annual flood counts across major suppliers, 1986–2022. *Panel B.* Ratio of each importer's full fixed-share flood-exposure variance to its variance under an independent-shock benchmark; values above one indicate that cross-supplier covariance raises exposure variance.

3. Empirical Strategy

The empirical strategy follows a supplier shock through the network. We first compare international with constructed domestic trade margins, then estimate substitution across existing supplier links, test whether correlated risk weakens that response, and finally use the 2011 Thailand floods as a sharper event-based test.

3.1 International versus domestic trade margins

We begin with a pooled structural-gravity specification using exporter-year, importer-year, and pair fixed effects (Anderson and van Wincoop, 2003; Yotov et al., 2016):

$$E[T_{ijt} \mid Z_{ijt}] = \exp\{\beta_1(Flood_{it} \times Intl_{ij}) + \beta_2(Flood_{it} \times SEA_i \times Intl_{ij}) + \pi_{it} + \chi_{jt} + \mu_{ij}\}. \quad (3)$$

$Intl_{ij}$ identifies international observations and SEA_i Southeast Asian exporters. Exporter-year effects π_{it} absorb exporter-specific annual conditions and outward multilateral resistance; importer-year effects χ_{jt} absorb importer demand and inward multilateral resistance; and pair effects μ_{ij} absorb time-invariant bilateral factors. In the pooled model, β_1 is the relative international response for non-Southeast-Asian exporters, while $\beta_1 + \beta_2$ is the corresponding response for Southeast Asian exporters. We also estimate Equation (3) on the Southeast Asia sample alone as a robustness check.

These coefficients identify international shipments *relative* to the constructed domestic benchmark. They do not identify an absolute export response, deliberate reallocation, or export policy. Flood-related export responses in Southeast Asia provide a closely related empirical setting (Tembata and Takeuchi, 2018). The gravity exercise is background to the network analysis, which is the focus of the paper.

3.2 Rival-supplier substitution and correlated risk

For each importer–supplier pair, define leave-one-out rival exposure as

$$RivalExposure_{mjt} = \sum_{k \neq j} w^0_{mk} Flood_{kt} = FloodExposure_{mt} - w^0_{mj} Flood_{jt}.$$

The baseline dyadic PPML specification is

$$E[Trade_{mjt} \mid Z_{mjt}] = \exp\{\alpha_{mj} + \delta_t + \beta_1 Flood_{jt} + \beta_2 RivalExposure_{mjt}\}. \quad (4)$$

Pair effects α_{mj} absorb time-invariant sourcing relationships and δ_t common shocks. A positive β_2 is consistent with substitution toward supplier j when historically important rivals flood. The baseline coefficient therefore uses within-pair changes in trade value combined with cross-importer differences in exposure to the floods of historically linked rival suppliers. We strengthen this specification with supplier-year fixed effects δ_{jt}, absorbing supplier-specific annual conditions—including own floods, supply shocks, prices, and trends—and importer-decade fixed effects $\delta_{m,dec}$, absorbing slower-moving importer trends. Under this specification, the remaining variation compares purchases from the same supplier across importers whose predetermined rival portfolios experience different flood realizations.

The portfolio test asks whether this response is weaker when the alternative portfolio carries more correlated risk:

$$\begin{aligned} E[Trade_{mjt}] = \exp\{&\alpha_{mj} + \delta_{jt} + \delta_{m,dec} + \beta_2 RivalExposure_{mjt} \\ &+ \theta_A(RivalExposure_{mjt} \times \widetilde{Amp}_m) + \theta_H(RivalExposure_{mjt} \times \widetilde{HHI}_m)\}. \end{aligned} \quad (5)$$

$\widetilde{Amp}_m$ is the standardized amplification factor and $\widetilde{HHI}_m$ standardized baseline supplier concentration. The portfolio prediction is $\theta_A < 0$: substitution should be weaker when alternatives co-flood. HHI separates covariance from concentration per se.

3.3 Identification and inference

The leave-one-out construction imposes an important fixed-effect constraint that determines what can be identified in the continuous design. This is not a minor specification choice: the algebra of the exposure determines whether the coefficient can still be interpreted as a rival-supplier response:

$$RivalExposure_{mjt} = FloodExposure_{mt} - w^0_{mj} Flood_{jt}.$$

Importer-year fixed effects would absorb $FloodExposure_{mt}$ exactly, leaving $-w^0_{mj} Flood_{jt}$ and changing the estimand from rival exposure to an own-dependence-by-own-flood interaction. We therefore use pair, supplier-year, and importer-decade fixed effects for substitution. The saturated importer-year plus supplier-year specification is instead used to estimate the distinct dependence margin:

$$E[Trade_{mjt} \mid Z_{mjt}] = \exp\{\delta_{mt} + \delta_{jt} + \gamma(w^0_{mj} \times Flood_{jt})\}. \tag{6}$$

A positive γ means that historically more dependent importers purchase relatively more from a supplier in its flood years, conditional on both sets of fixed effects; we interpret this as consistent with limited short-run substitutability or supplier lock-in, not a specific structural friction.

Inference must also reflect concentrated exposure. Because about six effective supplier shocks drive the design, we report exporter-clustered standard errors, two-way exporter–importer clustering, and a Rademacher wild-cluster bootstrap (Adão, Kolesár, and Morales, 2019; Borusyak, Hull, and Jaravel, 2022). Fixing 1986–1990 shares removes contemporaneous reweighting but does not by itself establish exogeneity of all future exposure. The identifying assumption is that, conditional on the fixed effects, innovations in exporter flood exposure are not systematically driven by unobserved importer-specific demand shocks. Coefficient stability, the future-exposure placebo, and the event-based design therefore matter for interpretation. Supplier floods need not be mutually independent: their covariance is the object of the paper.

3.4 The 2011 Thailand floods

The continuous design pools a small number of large supplier shocks, so we complement it with the 2011 Thailand megafloods, among the costliest disasters in Thai history and a major disruption to the world's then-largest rice exporter (World Bank, 2012; Haraguchi and Lall, 2015). Let $ThaiDep_m$ be importer m's 2008–2010 import share from Thailand. For purchases from non-Thai suppliers over 2006–2016, we estimate

$$E[Trade_{mjt}] = \exp\left\{\alpha_{mj} + \delta_t + \sum_{k \neq 2010} \phi_k (ThaiDep_m \times \mathbf{1}[t = k])\right\}, \quad j \neq \text{THA}. \tag{7}$$

The ϕ_k trace differential purchases from alternatives by more Thailand-dependent importers relative to 2010 and provide a direct check for pre-event differential trends. A pooled version uses $ThaiDep_m \times Post_t$, with $Post_t = \mathbf{1}[t \geq 2012]$; we treat 2011 as the event year. This first exercise identifies rerouting toward non-Thai suppliers; it does not by itself show whether total rice import value was maintained.

To test whether alternatives actually diversify risk, let $AltCov_m$ be the baseline-share-weighted average flood correlation between non-Thai suppliers and Thailand. In the current implementation

these correlations use 1986–2022, so $AltCov_m$ is a long-run network characteristic rather than a strictly predetermined treatment variable; a pre-2011 measure is the preferred robustness check. On importer totals we estimate

$$E[Imports_{mt}] = \exp\{\alpha_m + \delta_t + \beta_1(ThaiDep_m \times Post_t) + \beta_2(ThaiDep_m \times Post_t \times \widetilde{AltCov}_m)\}. \quad (8)$$

Because $\widetilde{AltCov}_m$ is standardized, β_1 is the post-event total-import response associated with Thai dependence for an importer whose alternative portfolio has average covariance with Thailand. The portfolio prediction is $\beta_2 < 0$: among equally Thailand-dependent importers, those whose alternatives co-flood with Thailand should exhibit a weaker total-import response. Identification comes from cross-importer variation in pre-event Thai dependence across 166 importers. We cluster by importer, report two-way importer–supplier clustering, and bootstrap over importers. The episode is a sharper test of the mechanism, but not a pure flood experiment because contemporaneous Thai rice-market developments may also affect trade.

4. Results

4.1 Network structure and trade-margin response

The descriptive network evidence is the paper's firmest result. Thailand and the United States account for more than half of predetermined flood exposure, and major Asian suppliers co-flood. Cross-supplier covariance raises exposure variance by about 65 percent for the Philippines and 40 percent for Côte d'Ivoire relative to the independent-shock benchmark (Figure 2). Thus two importers with similar supplier counts can face very different climate risk depending on how supplier shocks move together.

The gravity estimates provide background evidence on trade margins. In the pooled model, the non-Southeast-Asia coefficient is $\beta_1 = -0.012$ and the additional Southeast Asia interaction is $\beta_2 = -0.148$. The implied Southeast Asian response is therefore $\beta_1 + \beta_2 = -0.160$ (SE 0.076). Estimating the same specification on the Southeast Asia sample alone gives -0.252 (SE 0.093). These coefficients compare international shipments with the constructed domestic benchmark; they do not identify absolute movements in either margin.

4.2 Rival-supplier substitution and correlated risk

In the baseline dyadic specification, a supplier's own flood has essentially no average association with trade value (-0.006, exporter-clustered SE 0.011), while rival exposure is positive (0.042, SE 0.012): purchases from an unaffected supplier rise when historically important alternatives flood. Under supplier-year and importer-decade fixed effects, however, the rival-exposure coefficient falls by about 75 percent to 0.011. Its exporter-clustered SE is 0.005, importer-clustered SE 0.008, two-way SE 0.006, and the exporter wild-cluster bootstrap gives $p \approx 0.06$. The future-rival-exposure placebo is 0.016 (SE 0.009). Because floods are serially correlated, this placebo may partly reflect shock persistence, but it reinforces our cautious reading: the continuous substitution margin is suggestive rather than precisely identified.

The correlated-risk moderation has the predicted sign. The interaction of rival exposure with the amplification factor is -0.007 alone and -0.012 when HHI is included, with SEs about 0.008–0.013. The HHI interaction is -0.007 (SE 0.010) and is less stable. Economically, these two moderators

capture different features of the network: HHI measures how concentrated the supplier portfolio is, while the amplification factor measures how strongly supplier shocks move together. The sign pattern points more toward correlated exposure than concentration alone, although the estimates are too imprecise to distinguish the two mechanisms sharply. With only about six effective shocks, the cross-importer moderation is necessarily imprecise. We therefore interpret it as directional support for the portfolio mechanism, not a decisive test.

4.3 Dependence, directional adjustment, and alternative suppliers

The saturated dependence specification yields $\gamma = 0.460$ (exporter-clustered SE 0.087; two-way SE 0.106): conditional on importer-year and supplier-year effects, historically more dependent importers purchase relatively more, in value, from a supplier in its flood years. This is consistent with limited short-run substitutability or supplier lock-in, but the outcome is trade value and the specification does not include pair fixed effects, so we do not interpret it as a within-pair causal effect or a specific friction.

Table 1. Climate shocks and adjustment across supplier networks.

Spec.	Design	Coefficient	Estimate	SE
Panel A. International versus domestic trade margins				
(1)	Pooled gravity	$Flood \times International$ (β_1)	-0.012	—
		$Flood \times SEA \times International$ (β_2)	-0.148	—
		SEA total: $\beta_1 + \beta_2$	-0.160^{**}	0.076
(2)	SEA robustness	$Flood \times International$	-0.252^{***}	0.093
Panel B. Rival-supplier substitution				
(3)	Baseline network	Own flood	-0.006	0.011
		Rival exposure	0.042^{***}	0.012
(4)	Strengthened network	Rival exposure	0.011	0.006
Panel C. Correlated risk, dependence, and placebo				
(5)	Portfolio moderation	Rival exposure × amplification	-0.012	0.013
		Rival exposure × HHI	-0.007	0.010
(6)	Dependence	Dependence × own flood	0.460^{***}	0.087
(7)	Placebo	Future rival exposure, $t+1$	0.016	0.009

Notes: Each numbered specification is estimated separately by PPML; coefficients within a numbered block come from the same regression. Specification (1) is the pooled gravity model in Equation (3); the SEA total is the post-estimation linear combination $\beta_1 + \beta_2$. The compact main table reports the standard error of the economically relevant SEA total; component standard errors for β_1 and β_2 are omitted from the table for brevity. Specification (2) re-estimates the gravity model on the Southeast Asia sample. Specification (3) includes importer–supplier pair and year fixed effects. Specifications (4), (5), and (7) include importer–supplier pair, supplier-year, and importer-decade fixed effects. Specification (6) includes importer-year and supplier-year fixed effects. Network regressions use fixed 1986–1990 supplier shares and 1991–2022 outcomes. Alternative clustering and wild-cluster inference are discussed in the text; for Specification (4), the exporter wild-cluster bootstrap gives $p \approx 0.06$. $^{**}p < 0.05$; $^{***}p < 0.01$.

Figure 4 shows where adjustment goes when fixed-share Thailand–Vietnam hub exposure rises. Purchases from India, Pakistan, and China respond positively. These estimates document directional rerouting within the existing network and heterogeneity in supplier risk profiles; they are not a causal estimate of the effect of covariance, which is the object of Equation (5).

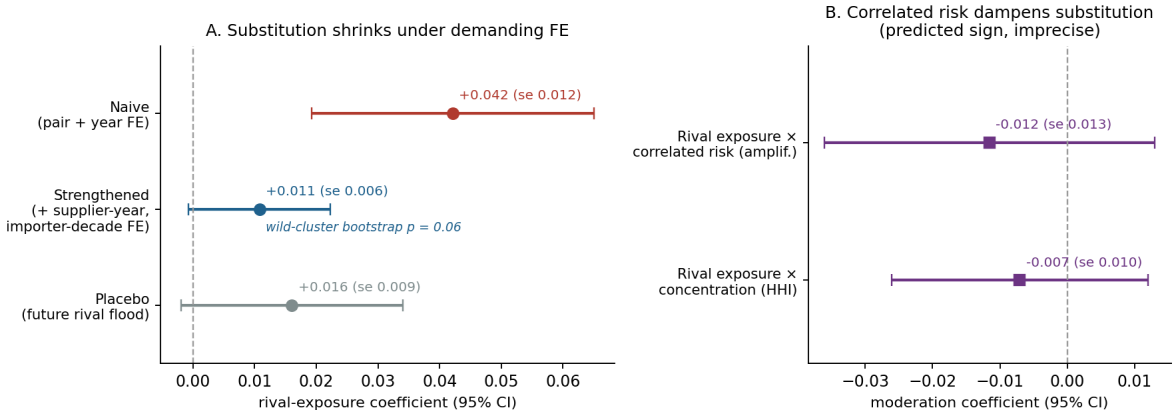


Figure 3. Supplier substitution and correlated-risk moderation. *Panel A.* The rival-exposure coefficient falls from 0.042 under pair and year fixed effects to 0.011 after adding supplier-year and importer-decade fixed effects. The future-exposure placebo is 0.016 (SE 0.009), while the strengthened estimate has an exporter wild-cluster bootstrap $p \approx 0.06$; bars report 95 percent confidence intervals. *Panel B.* Interactions of rival exposure with the exposure-amplification factor and supplier concentration (HHI). The correlated-risk coefficients are negative but imprecisely estimated.

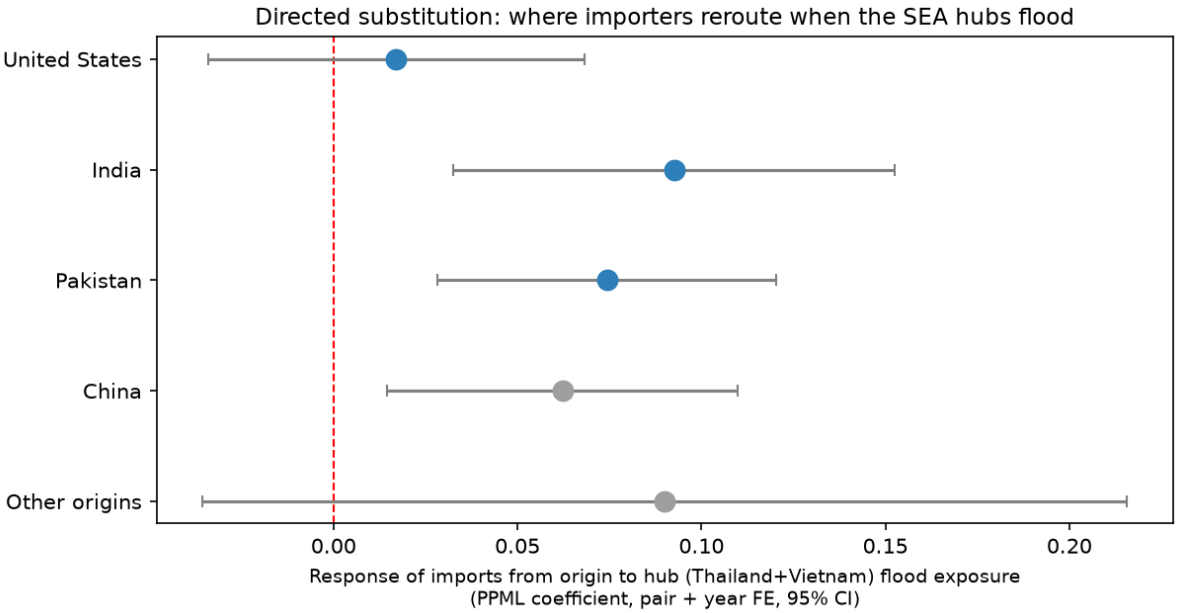


Figure 4. Directed substitution when Thailand–Vietnam hub exposure rises. Origin-specific PPML coefficients from importer–supplier-pair and year fixed-effect regressions using fixed 1986–1990 weights and 1991–2022 outcomes; bars report 95 percent confidence intervals.

4.4 The 2011 Thailand floods

The Thailand episode provides the sharper event-based evidence. In Figure 5A, differential purchases from alternative suppliers by Thailand-dependent importers are approximately flat in 2009–2010, then rise from about zero in 2010 to +0.95 in 2011 and +1.85 in 2012 and remain elevated through 2016. The pooled DID coefficient is +0.98 (two-way SE 0.37; wild-cluster-bootstrap $p = 0.003$). Economically, the pattern indicates that importers with greater pre-event exposure to Thailand shifted expenditure more strongly toward non-Thai origins after the shock. Coefficients in 2006–2007 are somewhat elevated, so we emphasize the local break around the event rather than uniform parallel trends over the full pre-period.

The portfolio result appears in total import value. For an importer with average alternative-supplier covariance, the Thai-dependence post coefficient is $\beta_1 = 0.17$ (SE 0.13). The triple-difference interaction is $\beta_2 = -0.83$ (SE 0.15, $z \approx 5.5$): importers whose non-Thai suppliers co-flood more strongly with Thailand show a weaker total-import response. Evaluated one standard deviation below the mean of alternative covariance, the implied effect is about +1.0; one standard deviation above, about −0.66. Thus, the same nominal access to alternatives provides less adjustment when those alternatives share Thailand's flood risk.

This evidence is sharper than the continuous moderation result but remains qualified. Thailand's 2011–2014 rice-pledging scheme accumulated public stocks and altered export flows over the same window, so the event is not a clean flood-only supply shock and part of the adjustment may operate through prices or policy. Some rerouting also went to regionally proximate suppliers such as Vietnam, which co-floods with Thailand. Finally, the current $AltCov_m$ uses 1986–2022 flood correlations and should be interpreted as a long-run network risk characteristic; a pre-2011 covariance measure is the preferred robustness check. Accordingly, we interpret the event as strong evidence consistent with the portfolio mechanism rather than a fully isolated causal effect of flood covariance.

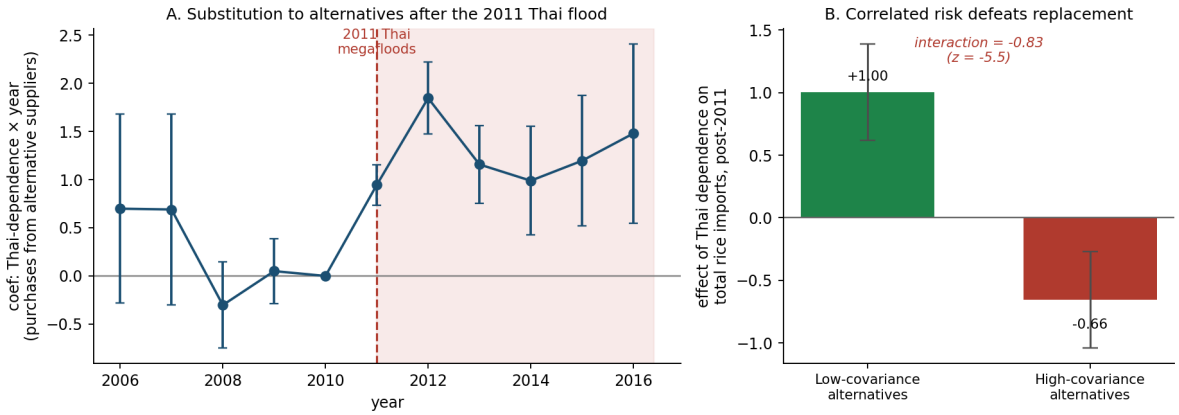


Figure 5. The 2011 Thailand floods. *Panel A.* Event-study coefficients on pre-event Thai dependence × year for purchases from alternative suppliers; 2010 is the reference year and bars report 95 percent confidence intervals. *Panel B.* Implied post-event effect of Thai dependence on total rice imports for importers with low and high alternative-supplier flood covariance (±1 SD of $AltCov_m$), based on Equation (8). The triple-difference interaction is −0.83 ($z \approx 5.5$).

5. Development Implications and Limitations

The development implication is that supplier diversification and effective risk diversification are different objects. A portfolio concentrated on one origin is exposed to that origin's shocks, but a portfolio spread across suppliers that co-flood can remain vulnerable. For import-dependent economies, resilience therefore depends on whether alternative origins remain available when a core supplier is disrupted. The amplification estimates show that this covariance channel is economically meaningful for several Gulf and monsoon-Asia importers, while hydroclimatically distinct origins can provide a stronger risk-diversification margin. This does not imply that importers should simply switch toward any particular origin; rather, conventional concentration or partner-count measures omit an economically relevant dimension of risk—the covariance structure of supplier shocks.

The empirical evidence has a clear hierarchy. Network concentration and shock covariance are robust descriptive facts. Continuous rival-supplier substitution is modest and only marginally significant under demanding inference, and its correlated-risk moderation is imprecise. The Thailand episode provides sharper support for the same mechanism, but the rice-pledging scheme, earlier pre-period movement, and long-run $AltCov_m$ measure limit a pure causal interpretation. The positive dependence interaction is consistent with lock-in but may also reflect prices or other relationship-specific frictions. These distinctions matter for policy: the paper does not estimate an optimal sourcing portfolio or show that diversification toward a particular supplier increases welfare. It shows instead that risk correlation is a dimension of trade exposure that partner counts and concentration measures alone do not capture.

Finally, all outcomes are trade values and ITPD-E domestic flows are constructed. The paper therefore does not identify physical quantities, prices, food availability, caloric consumption, or welfare. Stable import value could reflect offsetting movements in quantities and unit values, and the same caution applies to the dependence result. Severity-weighted flood measures, pre-2011 covariance, and separate quantity or unit-value outcomes are natural extensions.

6. Conclusion

This paper asks when an international sourcing network actually diversifies climate risk. The strongest evidence is that global rice sourcing is concentrated and flood risks are correlated across several major Asian suppliers, so supplier count alone is an incomplete measure of resilience. Importers appear to shift expenditure toward alternatives when rivals flood, but this continuous substitution margin is modest and imprecise under demanding specifications. The 2011 Thailand episode provides sharper evidence that Thailand-dependent importers rerouted toward alternatives and that total import value adjusted less when those alternatives had higher flood covariance with Thailand. Together, the results link the structure of the supplier network to the margin through which importers attempt to absorb a climate disruption.

The central distinction is therefore between having alternative suppliers and having *diversifying* alternative suppliers. Trade can buffer localized climate shocks only when the risks embedded in alternative links are sufficiently independent. This shifts the resilience question from the count of trade links toward the risk structure of the sourcing portfolio. It also provides a simple interpretation of why two countries with similar supplier counts can face very different exposure to the same class of climate hazard. For food-importing economies, trade-based climate resilience depends on the covariance structure of supplier risks, not simply on the number of trading partners.

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