Product Networks using Language Models Measurement and an Application to On-Shoring

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BBC Home News Sport

NEWS

Why firms are bringing their manufacturing back home

FINANCIAL TIMES

Donald Trump steps up warnings to US business over offshoring

Forbes

FORBES > BUSINESS > MANUFACTURING

Covid Is Fading, But Reshoring Isn't

News provider of the year

The Guardian UK

Economics viewpoint

Globalisation is not dead, but it is fading: 'glocalisation' is becoming the new mantra

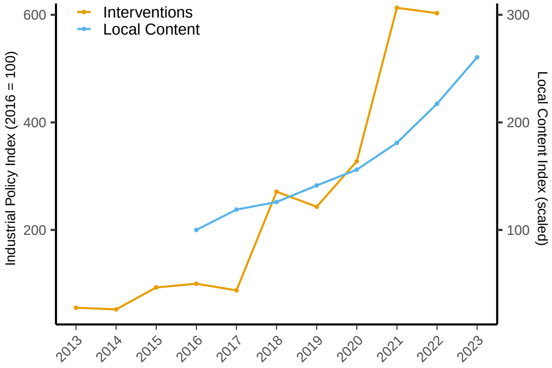
The New York Times

Supply Chain Woes Prompt a New Push to Revive U.S. Factories

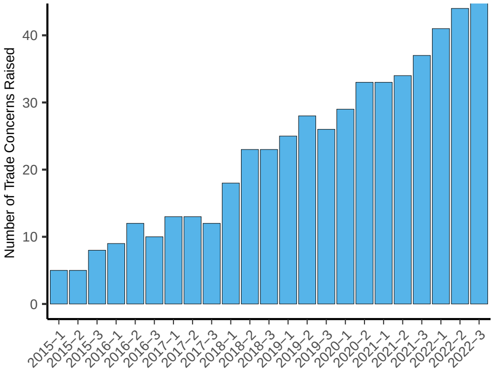
Companies are testing whether the United States can regain some of the manufacturing output it ceded in recent decades to China and other countries.

Rising trade barriers/disputes

Rising industrial policy

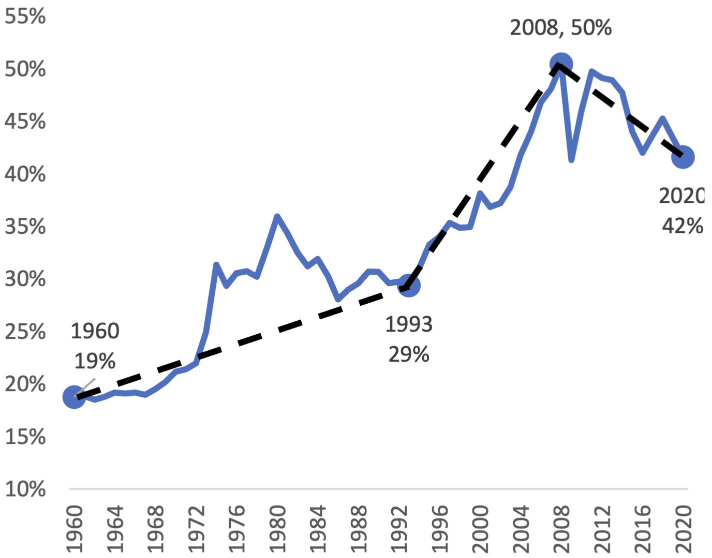


Increasing trade disputes



Source: Left shows keyword hits from news corpus on 'local content' policies, and industrial policy interventions. Right shows WTO trade disputes.

World goods trade as percent of world GDP



This paper

- Identify how trade shocks influence
  - On-shoring, aka ‘reshoring’, ‘localization’
  - Industrial transformation

- Build, validate and deploy a new production-network
  - Leverage novel AI/LLM tools to build a graphical dataset
  - Recovers vertical relationships across $5,000+$ HS products
  - Contrast to other measurement approaches e.g. SUTs/IOTs

- Two empirical applications:
  - Global impact of reduced form supply-shocks
  - Difference-in-difference study of Qatar blockade

Literature

- **Production-network representations**
  Text-based Frésard et al. (2019) Based on Input-Output tables Andersen et al. (2022); Karbevska & Hidalgo (2023); Fally (2012); Antràs et al. (2012); Antràs & Chor (2018) Administrative firm-to-firm transaction data Bernard & Moxnes (2018); Johnson (2018) General discussions Freeman & Baldwin (2020); Antràs (2020) US-China trade war Garred & Yuan (2024); Alfaro & Chor (2023); Crosignani et al. (2023); Fajgelbaum et al. (2020); Fetzer & Schwarz (2021); Handley & Limão (2017); Feenstra & Jensen (2012)
- **Trade shocks and their propagation**
  Japan earthquake Boehm et al. (2019) Brexit Freeman et al. (2022); D. Baqaee & Farhi (2021); Alabrese et al. (2024); Costa et al. (2019) Political tensions and war Gopinath et al. (2024); Korovkin & Makarin (2023); Bachmann et al. (2022); Nigmatulina (2023); Funke et al. (2023) Theory D. R. Baqaee & Farhi (2019); Acemoglu et al. (2015, 2012)
- **(Smart?) Industrial policy**
  Protectionism and technology adoption Juhász et al. (2023); Juhász (2018) Trade and resilience of production networks Grossman et al. (2023); Elliott et al. (2022); Koren & Tenreyro (2013)

Outline

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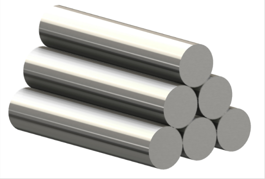
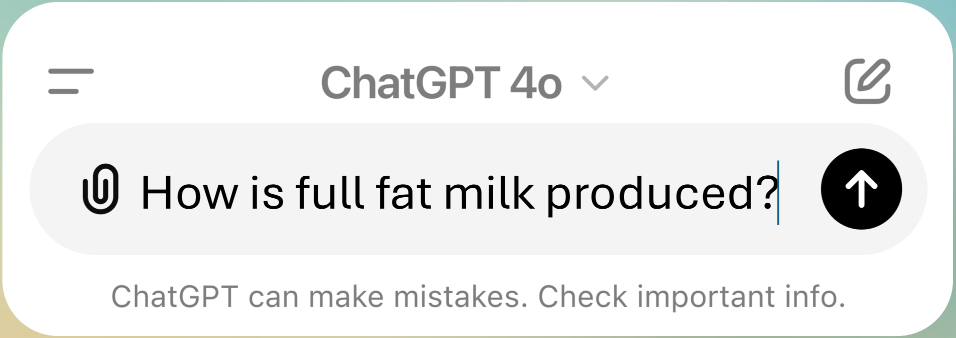
Measurement Challenge

- Want to assess how **trade shocks** propagate through **production networks**
- But how to measure set of relevant **upstream goods**?
- Ideal measurement of production-linkages
  - Based on actual production processes
  - Not just market transactions
  - Highly granular to compliment rich trade data


Introducing AIPNET

- AI-built Production Network (AIPNET)
- Leverages power of AI/LLM to systematically identify network structure
- Trained, tuned, and validated for this purpose
- Capable of ‘understanding’ technical requirements of over $5,000$ Harmonized System (HS) product groups


ChatGPT 4o
How is full fat milk produced?
ChatGPT can make mistakes. Check important info.

How is full fat milk produced?

Full-fat milk, also known as whole milk, is produced through a series of processes that maintain its natural fat content, typically around 3.25% in most countries. Here's a breakdown of the process:

1. Milking the Cow:

- The milk production process begins with cows being milked, either manually or using machines. Modern dairies use automated milking machines to ensure hygiene and efficiency.

2. Filtration and Cooling:

- After the cow is milked, the raw milk is immediately filtered to remove any impurities (such as dirt or hair) that may have been introduced during the milking process.
- The milk is then rapidly cooled to about 4°C (39°F) to prevent bacterial growth before being transported to a processing plant.

3. Separation:

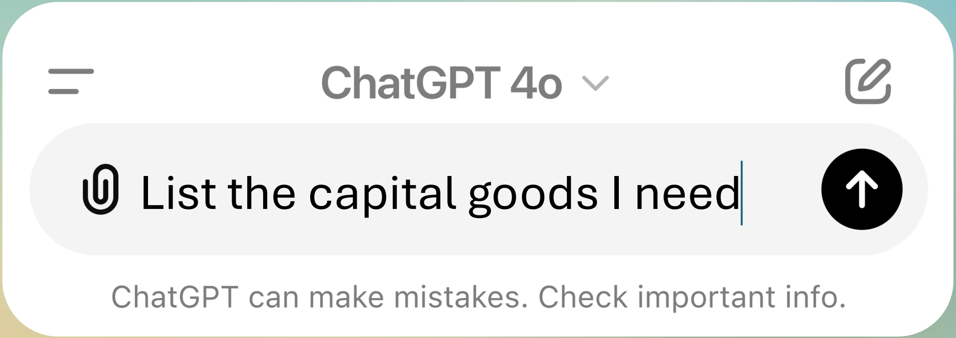
- At the dairy plant, the raw milk undergoes a separation process where the cream is separated from the skim milk using a centrifuge. This allows the dairy to control the fat content in the final product.
- For full-fat or whole milk, a portion of the cream is added back to achieve the desired fat percentage, typically around 3.25%.

4. Pasteurization:

- Pasteurization involves heating the milk to a specific temperature (around 72°C or 161°F) for about 15–20 seconds and then cooling it quickly. This process kills harmful bacteria while preserving nutrients.

5. Homogenization:

- In homogenization, the milk is forced through small holes at high pressure, breaking down the fat molecules so they remain evenly distributed throughout the milk. This prevents the cream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List the capital goods I need?

To produce full-fat milk on a dairy farm, you'll need several **capital goods** (long-term assets used in the production process). Here is a list of typical capital goods necessary for dairy farming:

1. Dairy Cows:

- High-quality dairy cows (such as Holstein, Jersey) are one of the most significant investments for milk production.

2. Milking Equipment:

- **Milking Machines**: Automated or semi-automated systems for milking cows efficiently.
- **Milking Parlors**: Specialized facilities designed for the milking process, including cow stalls and milking lines.

3. Cooling and Storage Equipment:

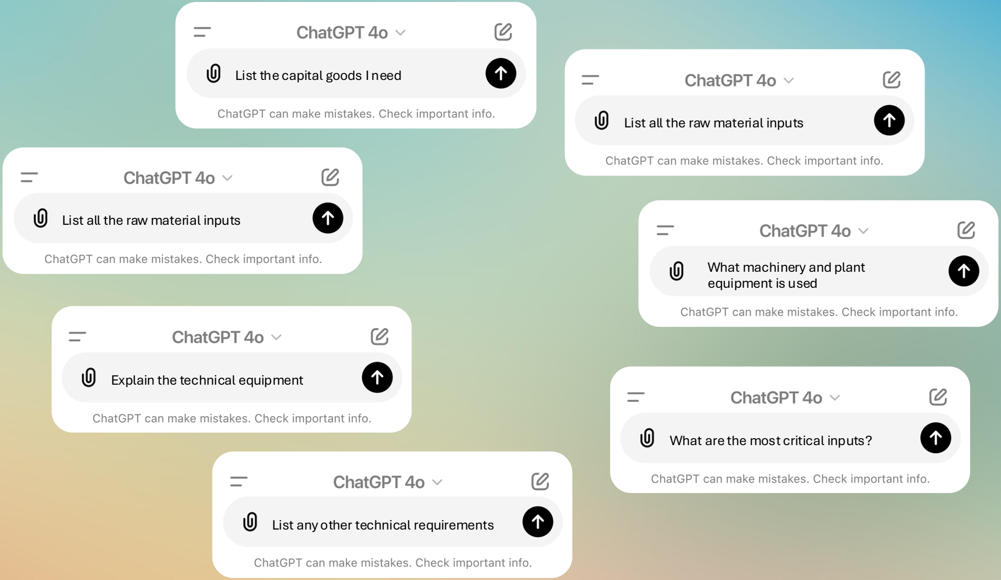
- **Bulk Cooling Tanks**: Large stainless steel tanks that cool and store raw milk before it's transported to processing facilities.
- **Milk Silos**: Large storage tanks for bulk milk before transportation or processing.

4. Processing Equipment:

- **Pasteurizers**: Equipment used to heat milk to a specific temperature to kill bacteria.
- **Homogenizers**: Equipment that breaks down fat molecules to ensure even distribution in milk.
- **Cream Separators**: Machines that separate the cream from the milk, useful for standardizing fat content.

5. Feed Production and Storage:

- **Tractors and Feed Mixers**: Essential for producing and delivering feed to the cows.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List the capital goods I need
ChatGPT can make mistakes. Check important info.
ChatGPT 4o
List all the raw material inputs
ChatGPT can make mistakes. Check important info.
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ChatGPT can make mistakes. Check important info.
ChatGPT 4o
What machinery and plant equipment is used
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ChatGPT 4o
Explain the technical equipment
ChatGPT can make mistakes. Check important info.
ChatGPT 4o
What are the most critical inputs?
ChatGPT can make mistakes. Check important info.
ChatGPT 4o
List any other technical requirements
ChatGPT can make mistakes. Check important info.

Milk

214 languages

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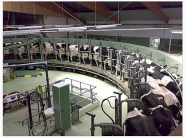
Contents hide

This article is about the fluid produced by the mammary glands of mammals. For the milk-like beverages derived from plants, see Plant milk. For other uses of the word, see Milk (disambiguation).


A glass of cow milk

Milk is a white liquid food produced by the mammary glands of mammals. It is the primary source of nutrition for young mammals (including breastfed human infants) before they are able to digest solid food.[1] Milk contains many nutrients, including calcium and protein, as well as lactose and saturated fat.[2] Immune factors and immune-modulating components in milk contribute to milk immunity. Early-lactation milk, which is called colostrum, contains antibodies and immune-modulating components that strengthen the immune system against many diseases. The US CDC agency recommends that children over the age of 12 months should have two servings of dairy milk products a day,[3] and more than six billion people worldwide consume milk and milk products.[4]


Cows in a rotary milking parlor

As an agricultural product, dairy milk is collected from farm animals, mostly cattle. In 2011, dairy farms produced around 730 million tonnes (800 million short tons) of milk[5] from 260 million dairy cows.[6] India is the world's largest producer of milk and the leading exporter of skimmed milk powder.[7][8] New Zealand, Germany, and the Netherlands are the largest exporters of milk products.[9] Between 750 and 900 million people live in dairy-farming households.[4]

Etymology and terminology

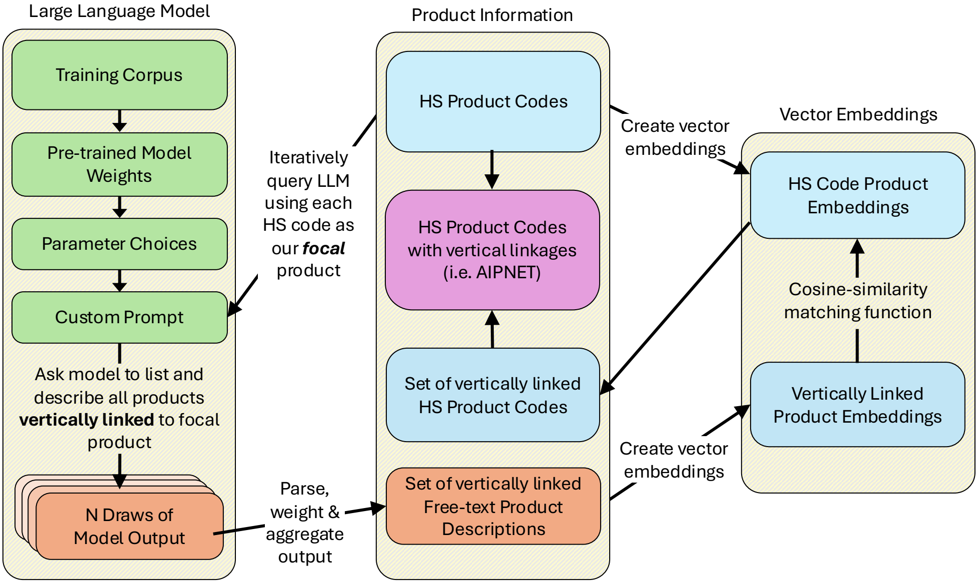
The term *milk* comes from "Old English *meoluc* (West Saxon), *milc* (Anglian), from Proto-Germanic **meluks* "milk" (source also of Old Norse *mjolk*, Old Frisian *melok*, Old Saxon *miluk*, Dutch *melk*, Old High German *miluh*, German *Milch*, Gothic *miluks*)".[10]

Since 1961, the term *milk* has been defined under Codex Alimentarius standards as "the normal mammary secretion of milking animals obtained from one or more milkings without either addition to it or extraction from it, intended for consumption as liquid milk or for further processing."[11] The term *dairy* refers to animal milk and animal milk production.

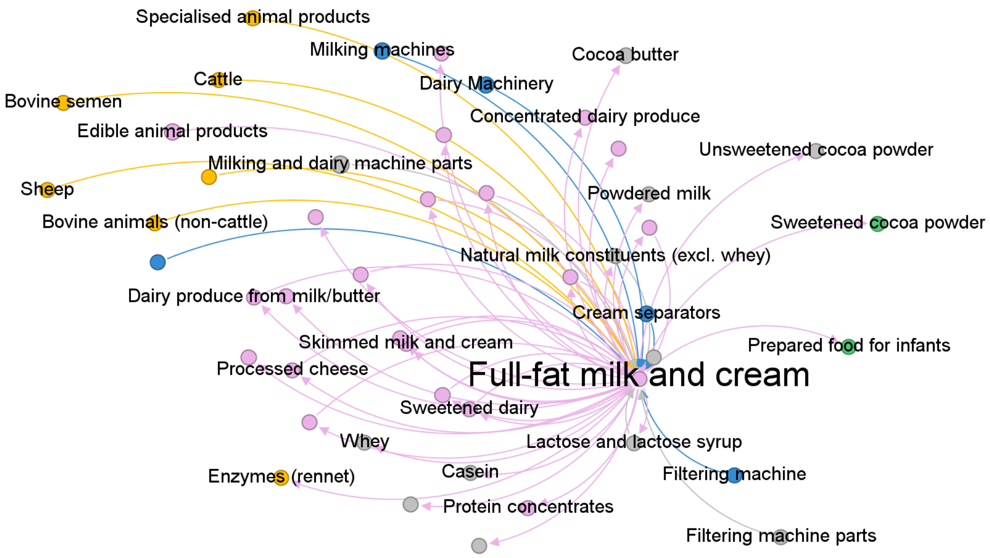
Beyond ChatGPT

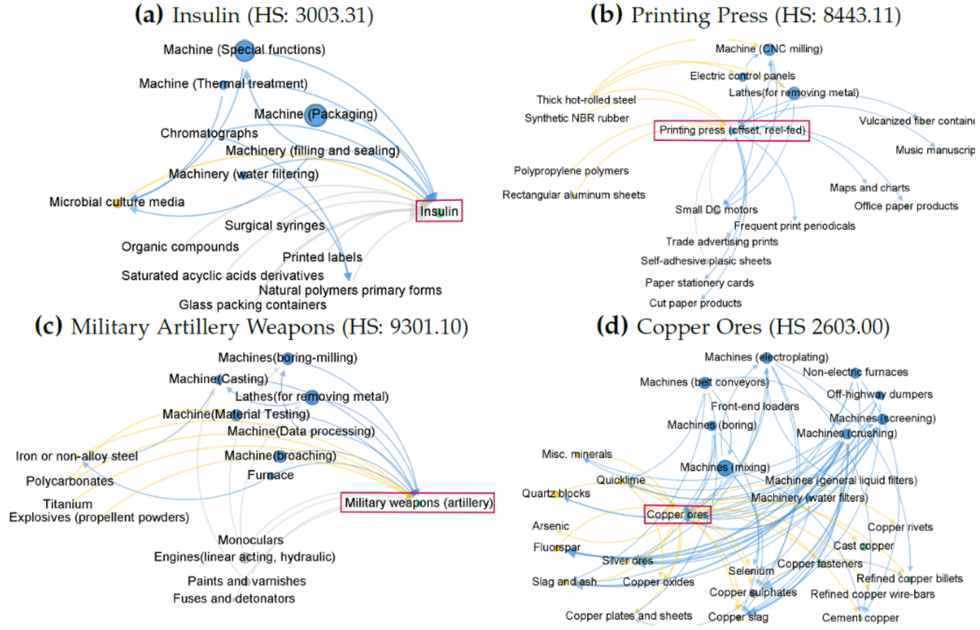
- Our LLM is trained on production process text
- Utilizes a refined prompting strategy for bootstrap learning
- Extracts structured output
- Iterative sampling
- Adversarial AI evaluations
- Match free-text responses to HS Code nomenclature

Flowchart of steps to build AIPNET



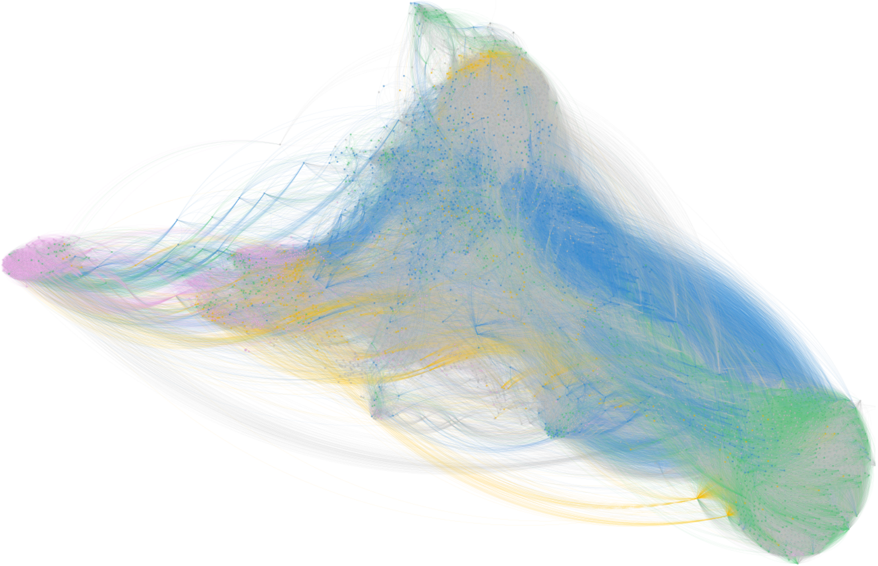
Example: Full-fat milk and cream





(a) Insulin (HS: 3003.31)
Machine (Special functions)
Machine (Thermal treatment)
Machine (Packaging)
Chromatographs
Machinery (filling and sealing)
Machinery (water filtering)
Microbial culture media
Insulin
Surgical syringes
Organic compounds
Printed labels
Saturated acyclic acids derivatives
Natural polymers primary forms
Glass packing containers
(b) Printing Press (HS: 8443.11)
Machine (CNC milling)
Electric control panels
Lathes(for removing metal)
Thick hot-rolled steel
Synthetic NBR rubber
Printing press (offset, reel-fed)
Vulcanized fiber containe
Music manuscrip
Polypropylene polymers
Rectangular aluminum sheets
Maps and charts
Office paper products
Small DC motors
Frequent print periodicals
Trade advertising prints
Self-adhesive plasic sheets
Paper stationery cards
Cut paper products
(c) Military Artillery Weapons (HS: 9301.10)
Machines(boring-milling)
Machine(Casting)
Lathes(for removing metal)
Machine(Material Testing)
Machine(Data processing)
Iron or non-alloy steel
Machine(broaching)
Polycarbonates
Furnace
Titanium
Explosives (propellent powders)
Military weapons (artillery)
Monoculars
Engines(linear acting, hydraulic)
Paints and varnishes
Fuses and detonators
(d) Copper Ores (HS 2603.00)
Machines (electroplating)
Non-electric furnaces
Machines (belt conveyors)
Off-highway dumpers
Front-end loaders
Machines (screening)
Machines (boring)
Machines (crushing)
Misc. minerals
Machines (mixing)
Quicklime
Machines (general liquid filters)
Quartz blocks
Machinery (water filters)
Copper ores
Arsenic
Copper rivets
Cast copper
Fluorspar
Silver ores
Copper fasteners
Selenium
Refined copper billets
Slag and ash
Copper oxides
Copper sulphates
Refined copper wire-bars
Copper plates and sheets
Copper slag
Cement copper

AI-built Production Network (AIPNET)



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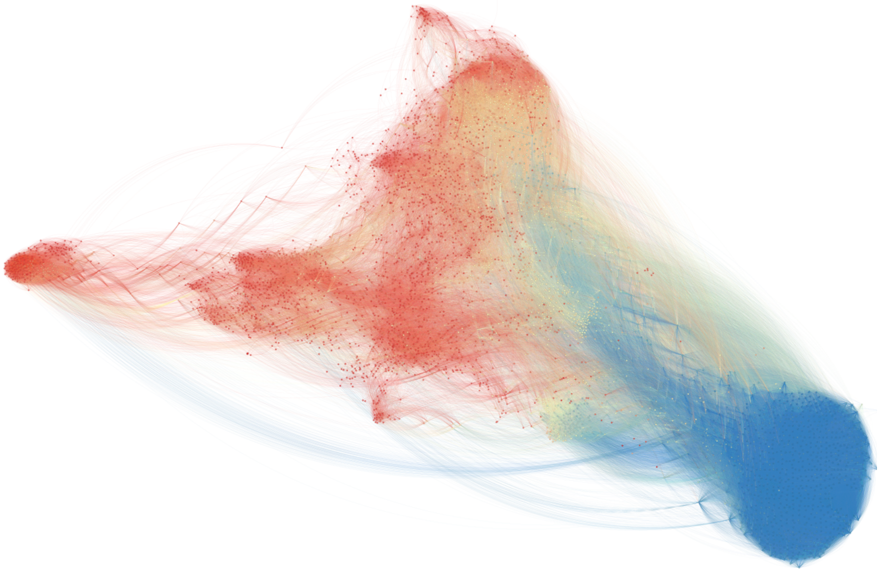


Network Properties of AIPNET (HS6 Level)

	Iteration			Edge Overlap			Temperature		
	1	2	3	>7	>8	>9	0.2	0.6	1.0
Nodes	5,080	5,080	5,080	5,079	5,079	5,078	5,080	5,080	5,080
Edges (000s)	1,538	1,541	1,538	990	830	625	2,115	2,246	2,219
Avg. Deg.	606	607	606	390	327	246	833	884	874
Density	.060	.060	.060	.038	.032	.024	.082	.087	.086
Clust. Coeff.	.504	.504	.504	.593	.605	.610	.478	.482	.485
Assort.	.311	.314	.310	.482	.501	.498	.175	.180	.197

Outline

Validation

- Compare AIPNET to Input-Output Tables (IOTs)
  - Recast Product-level network into IOT structure
  - Compare Input-use intensity to AIPNET product linkages
- Compare to product-level supply chain position measures:
  - 'Upstreamness' (Fally, 2016; Antras et al. 2018)
  - Product Complexity Index (PCI) (Hausman & Hidalgo, 2014)
- Conduct perturbation/placebo tests
  - Uses Erdos-Renyi network perturbations
  - Evaluate validation exercises of more 'random' networks

AIPNET strongly correlates with Input-Output Tables

Figure 3: US

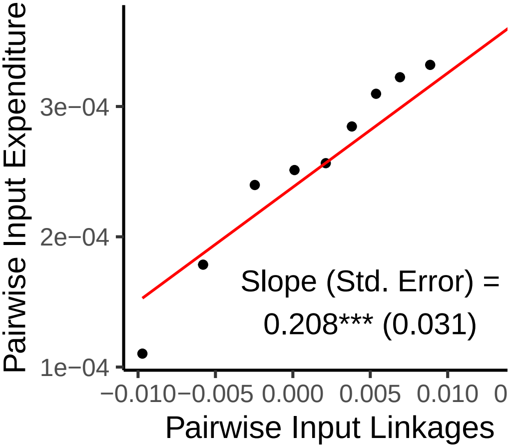
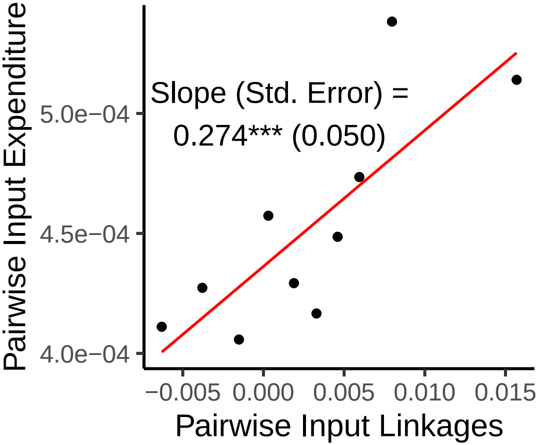
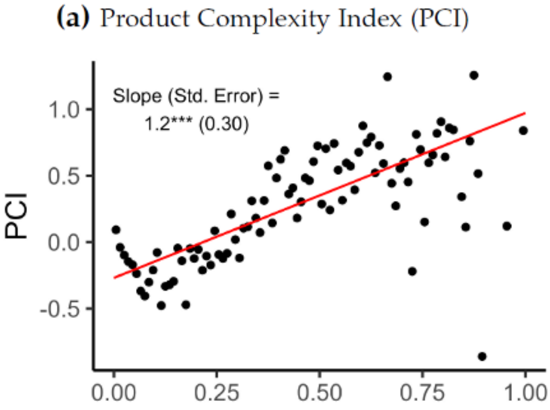
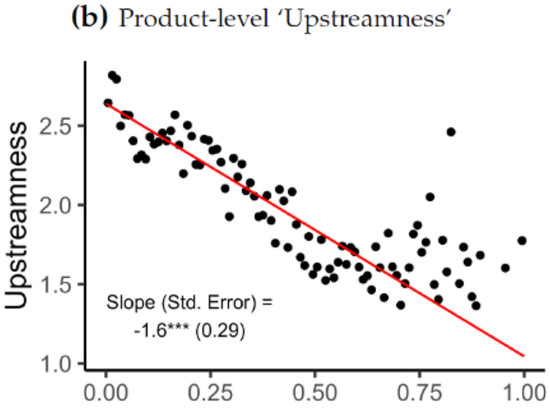


Figure 4: Mexico

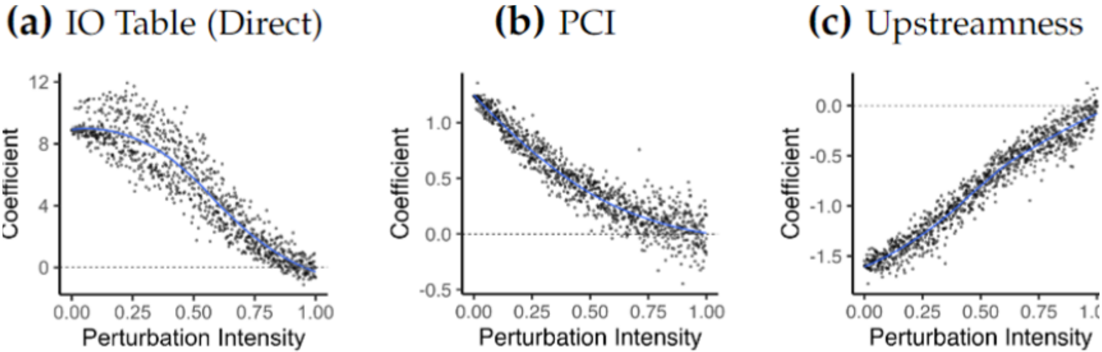


Comparison to Upstreamness and PCI





Perturbing network attenuated validation estimates



Final Thoughts on Measurement

- AIPNET is not perfect...
  - Discrete edges, but can address econometrically
  - Assumes globally homogeneous technical processes
- But it has several notable strengths:
  - Highly granular
  - Can be used directly with trade data
  - Accurately recovers technical requirements
  - Standardized nomenclature
  - Uncensored by market configuration / vertical integration
  - Strongly correlated with existing network representations

Outline

Measurement

Validation

Descriptive Results

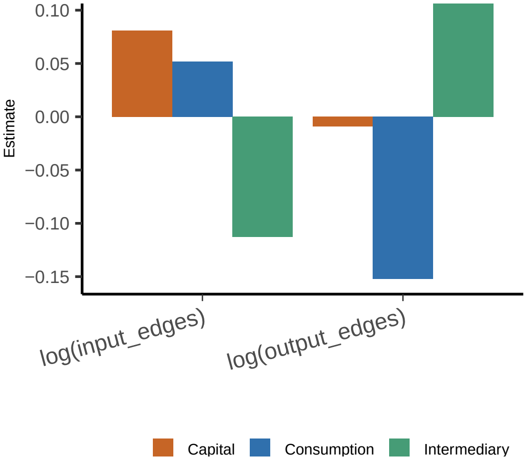
Price Shocks and On-shoring

Causal Study

Comparison with classification systems

Figure displays correlation between BEC classification and the of inputs vis-a-vis the of outputs for any given product

- As the of input edges is increaseing, a good is more likely to be a capital or consumption good.
- As the of output edges is (decreasing) increasing, a good is (less) more likely to be an intermediate good.



Upstreamness in Production Networks

$$\mathbf{U} = \mathbf{1} + \mathbf{D}^{-1}\mathbf{W}\mathbf{U}$$

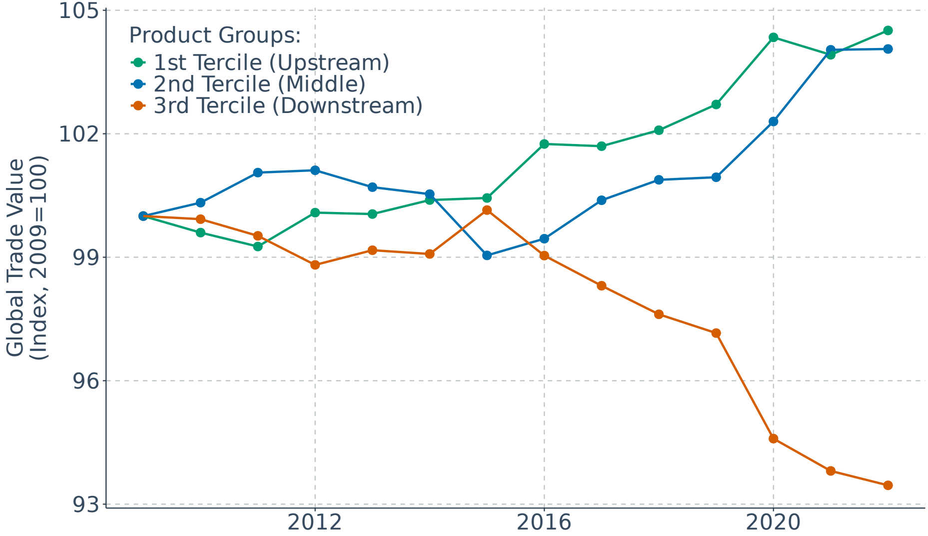
where:

- $\mathbf{U}$ is the vector of upstreamness scores
- $\mathbf{W}$ is the adjacency matrix of the production network
- $\mathbf{D} = \text{diag}(\mathbf{W}\mathbf{1})$ is the diagonal matrix of out-degrees
- $\mathbf{1}$ is a vector of ones

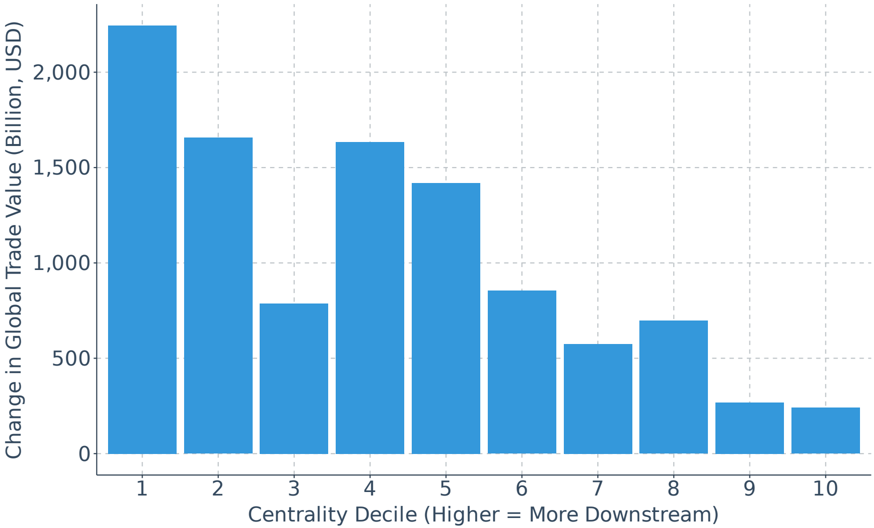
Interpretation:

- U_i measures average steps to final demand for product i
- $U_i = 1$: product is directly consumed (no outgoing links)
- $U_i > 1$: product is an input for other products in the network
- Higher U_i: more upstream in the production chain

Network position predicts divergent global trend since 2016

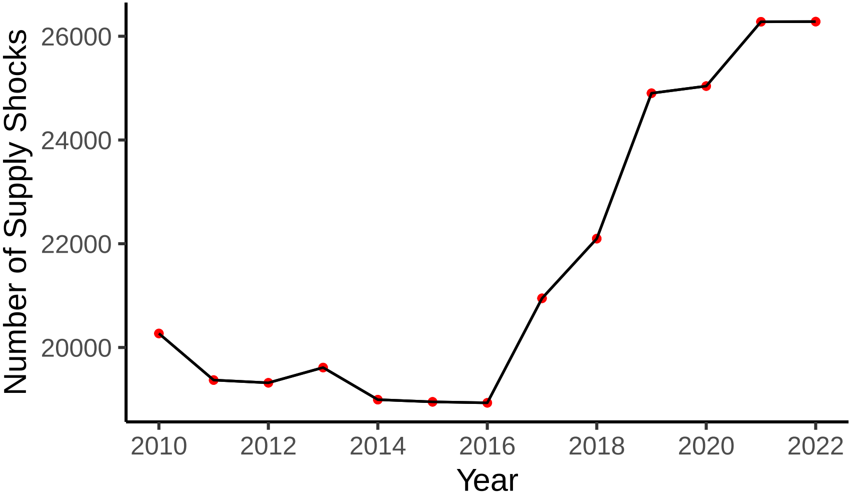


More upstream products saw biggest increase in trade value

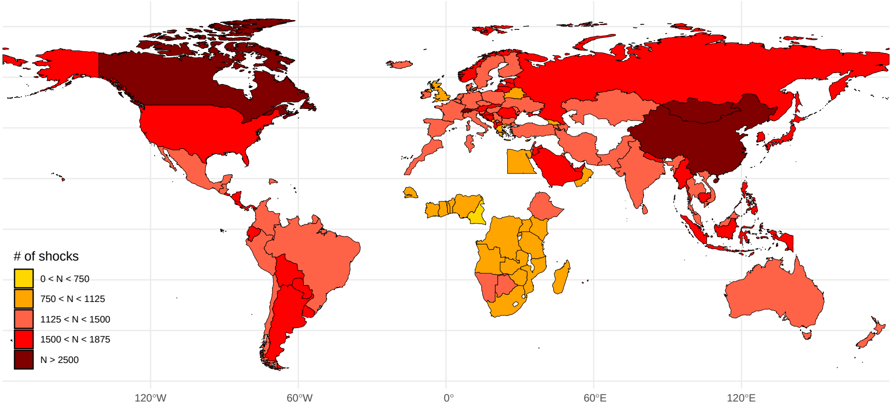


Outline

Persistent Price Shocks



Geographic distribution of price shocks



Cross-Country Evidence: Global Trade Dynamics

- Uses exporter×importer×product trade data for 200 countries, 2010-2022
- Study broad trends by network centrality
- Econometric specification:
  - Each observation is a triple: $\{upstream = i, downstream = j, destination = c\}$
  - Price shock dummy variables: $S = \{0, 1\}$
  - Network Linkages: $W_{ij} = \{1, 0\}$
  - Doubly robust network inference estimator
  - Highly saturated controls

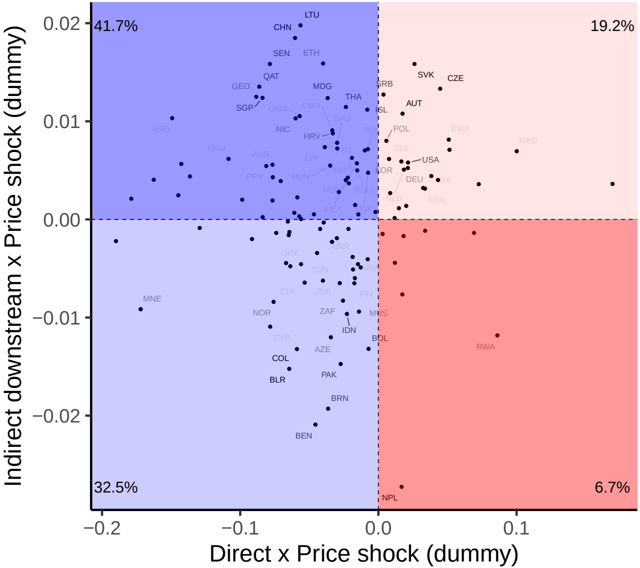
$$Ln(\text{Import}_{jct}) = \beta_1(S_{ict} \times W_{ij}) + \beta_2(S_{jct} \times W_{ij}) + \alpha_{ijc} + \gamma_{jtc} + \epsilon_{ijt}$$

Direct and Indirect Supply Shocks

Dependent variable:	log(Import Value)
AIPNET $\times$ Indirect upstream price shock (dummy)	1.4***
	(0.0004)
AIPNET $\times$ Direct own price shock (dummy)	-2.3***
	(0.0046)
R^2	0.952
Observations	1.73B

Notes: Dyadic regression results. Controls: country-by-dyad FE, country $\times$ HS2 $\times$ year FE. Parametric estimates with time-varying supply shock measures. SE clustered at HS2 $\times$ HS2 dyadic level. Significance: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

On-shoring estimate by country estimate this by country



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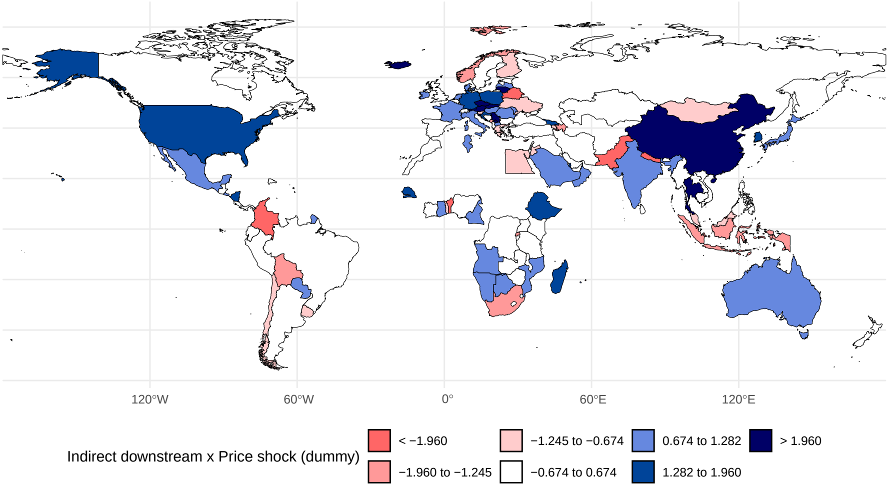

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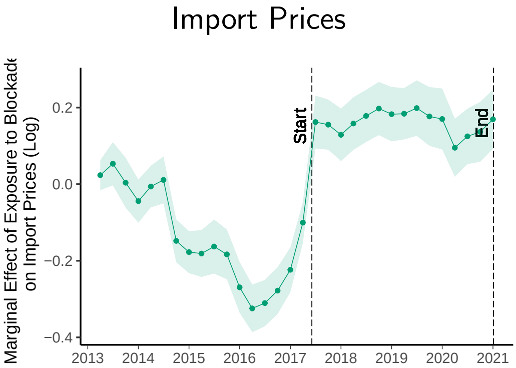
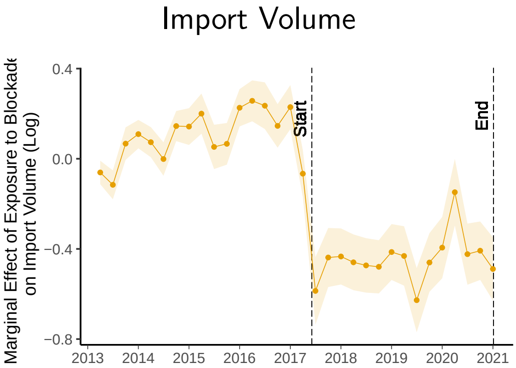
Causal Study

Qatar Case Study: Blockade Impact on Trade

- Analysis of the 2017 Qatar diplomatic crisis and trade blockade
- Utilizes admin data from customs authority on monthly trade
- Focus on changes in import patterns and onshoring efforts
- Examination of direct and indirect effects on trade

Blockade Dramatically Shifted Trade Flows





Unpacking the Import Equation

$$Ln(\text{Import}_{jt}) = \beta_1(E_i \times \text{Post}_t) + \beta_2(E_j \times \text{Post}_t \times W_{ij}) + \alpha_{ij} + \gamma_{jt} + \epsilon_{ijt}$$

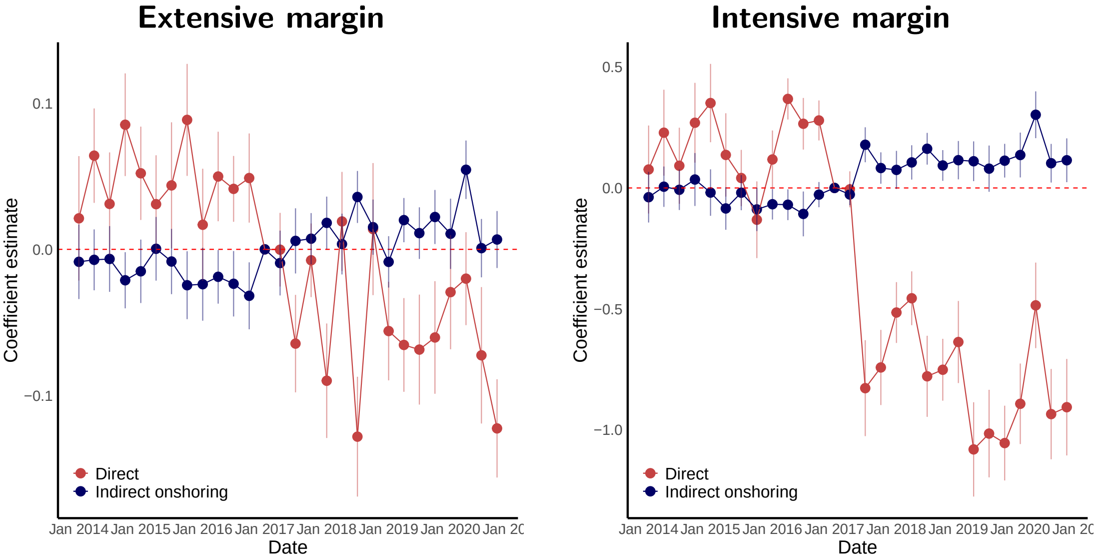
- E_i: Exposure of product i to blockade based on pre-blockade import share
- W_{ij}: Dummy for whether i is used as an input to produce j
- β_1: Direct effect of blockade exposure
- β_2: Indirect effect of blockage exposure

Impact of product-level blockade exposure on imports

	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable	Import > 0			ihs(import)		
Blockade $\times$ Exposure (Direct)	-0.0218**		-0.0236**	-0.7179***		-0.7389***
	(0.0105)		(0.0105)	(0.1374)		(0.1371)
Blockade $\times$ Exposure (Indirect)		0.0149***	0.0176***		0.1274*	0.2120***
		(0.0053)	(0.0052)		(0.0694)	(0.0658)
R^2	0.55373	0.55371	0.55375	0.66042	0.66017	0.66044
Observations	31,405,416	31,405,416	31,405,416	31,405,416	31,405,416	31,405,416
Dyad FE	X	X	X	X	X	X
Time FE	X	X	X	X	X	X

Notes: Dyadic-clustered standard-errors in parentheses. Significance Codes: ***: 0.01, **: 0.05, *: 0.1.

Blockade caused upstream import substitution (on-shoring)



Conclusion

- We construct and validate the AI-built Production Network (AIPNET)
- Allows us to study vertical substitution up the value-chain
- Three main results:
  - Global trade patterns shifting towards upstream goods
  - Structural breaks in unit-prices correlate with vertical substitution
  - Exogenous blockade event leads to onshoring via upstream substitution
- Next steps:
  - 'Place-based AIPNET' ie Local Production Networks
  - Public release of AIPNET (October, 2024)

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