

# AI-Generated Production Networks: Measurement and Applications to Global Trade

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LSE

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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

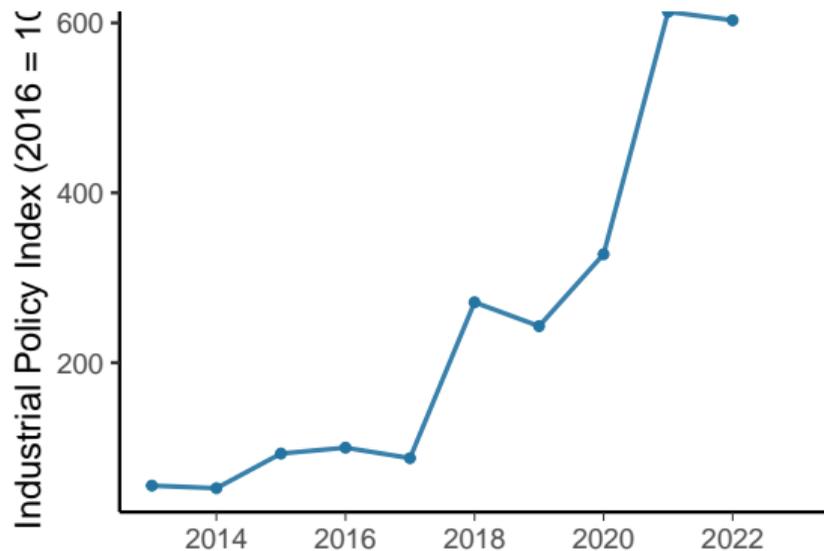
☰ **The New York Times** 👤

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

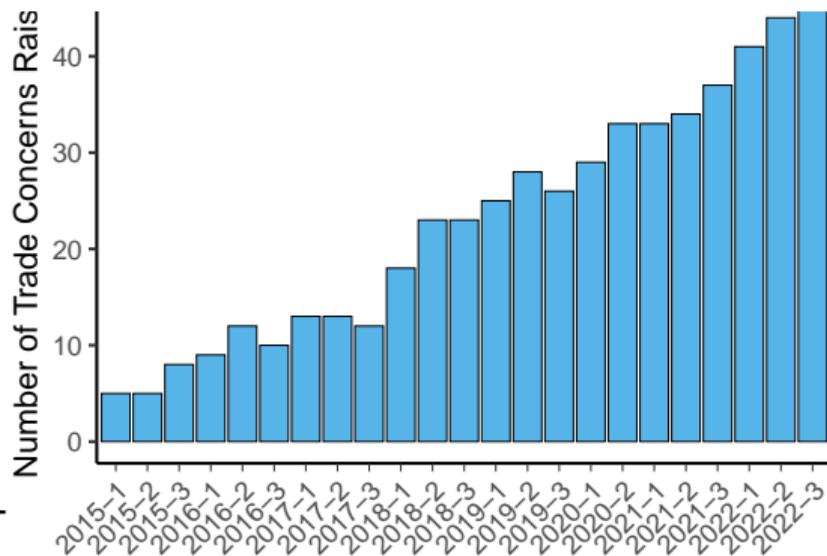
Companies are testing whether the United States can regain some of the manufacturing output it ceded in recent decades to China and other countries.

# Rising trade barriers/disputes

## Rising industrial policy

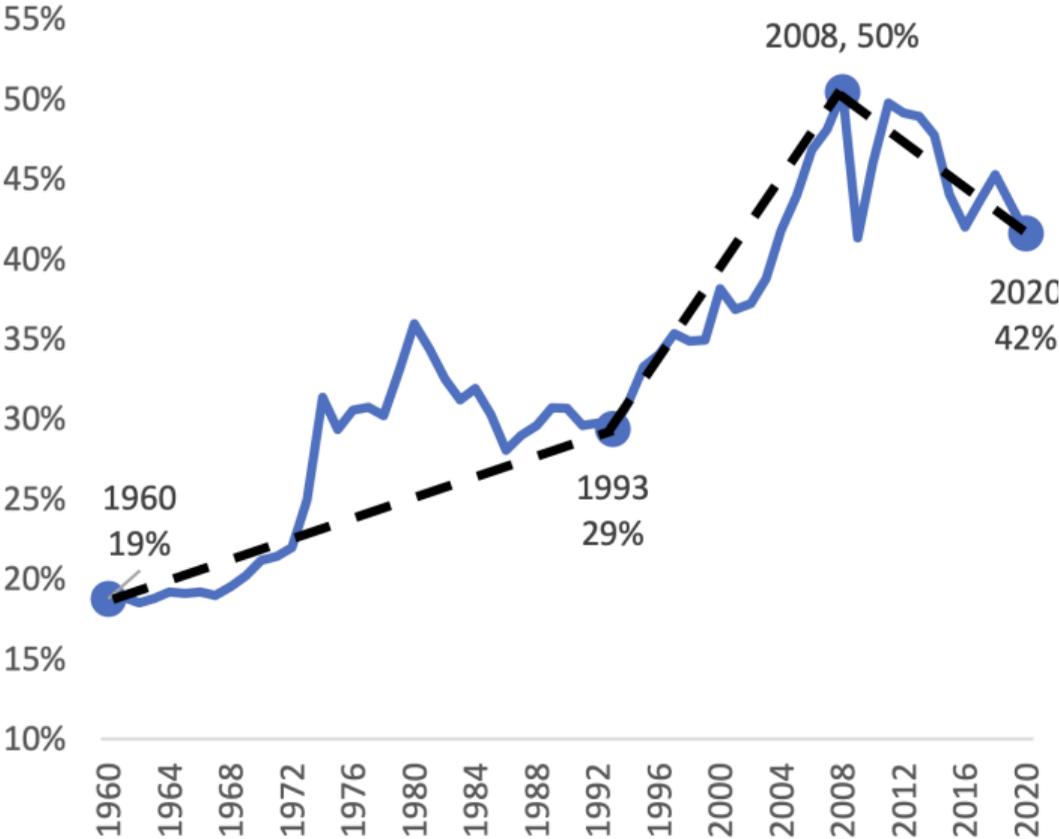


## Increasing trade disputes



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. (2020) Based on Input-Output tables Andersen et al. (2022); Karbevaska & Hidalgo (2023); Fally (2012); Antràs et al. (2012); Antràs & Chor (2018) Administrative firm-to-firm transaction data Johnson (2018) General discussions Freeman & Baldwin (2020) US-China trade war Garred & Yuan (2024); 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); Baqaee & Farhi (2021); Alabrese et al. (2024); Costa et al. (2019) Political tensions and war Gopinath et al. (2024); Bachmann et al. (2022) Theory Baqaee & Farhi (2019); Acemoglu et al. (2015, 2012)

## ▶ **(Smart?) Industrial policy**

Protectionism and technology adoption Juhász et al. (2023) Trade and resilience of production networks Elliott et al. (2022)

# Outline

Measurement

Validation

Global Patterns in Trade Data

Price Shocks and On-shoring

Onshoring Natural Experiment

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Measurement

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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

HS **190520** Food preparations; gingerbread and the like, whether or not containing cocoa



# HS 190520 Food preparations; **gingerbread** and the like, whether or not containing cocoa

## Gingerbread

[Article](#) [Talk](#)

From Wikipedia, the free encyclopedia

*For other uses, see [Gingerbread \(disambiguation\)](#).*

**Gingerbread** refers to a broad category of **baked goods** typically flavored with **ginger, cloves, nutmeg** and **cinnamon** and sweetened with **honey, sugar, or molasses**. Gingerbread foods vary, ranging from a moist loaf cake to forms nearly as crisp as a **ginger snap**.<sup>[1]</sup>

### Etymology [\[ edit \]](#)

Originally, the term gingerbread (from Latin *zingiber* via Old French *gingebras*) referred to preserved *ginger*. It then referred to a confection made with honey and spices. Gingerbread is often used to translate the French term *pain d'épices* (lit. 'spice bread') or the German and Polish terms *Pfefferkuchen* and *Piernik* respectively (lit. 'pepper cake' because it used to contain pepper) or *Lebkuchen* (of unclear etymology; either Latin *libum*, meaning "sacrifice" or "sacrificial bread," or German *Laib* for loaf or German for life, *leben*). Pepper is also referenced in regional names like Norwegian *pepperkaker* or Czech *perník* (originally *peprník*).<sup>[2]</sup>

The meaning of gingerbread has evolved over time. For centuries the term referred to a traditional European *tr* traditionally used to make *gingerbread men*. In the United States the first known recipe for "Soft gingerbread is

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## Baking

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"[Baked](#)" redirects here. For cannabis intoxication, see *Effects of cannabis*. For the comedy web series, see *Baked (web series)*.

**Baking** is a method of preparing food that uses dry heat, typically in an **oven**, but can also be done in hot ashes, or on hot stones. The most common baked item is *bread*, but many other types of foods can be baked.<sup>[1]</sup> Heat is gradually transferred "from the surface of cakes, cookies, and pieces of bread to their center, typically conducted at elevated temperatures surpassing 300°F". Dry heat cooking imparts a distinctive richness to foods through the processes of caramelization and surface browning. As heat travels through, it transforms batters and doughs into baked goods and more with a firm, dry crust and a softer center.<sup>[2]</sup> Baking can be combined with *grilling* to produce a hybrid *bark*, a variant by using both methods simultaneously, or one after the other. Baking is related to *broasting* because the concept of the *massive oven* is similar to that of a *broaster pit*.



Recently baked bread

# HS 190520 Food preparations; **gingerbread** and the like, whether or not containing cocoa

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Freshly baked bread

## Oven

Article Talk

Read View src

From Wikipedia, the free encyclopedia

For clay ovens, see [Primitive clay oven](#). For other uses, see [Ovens \(disambiguation\)](#).

Not to be confused with [industrial furnace](#).

An **oven** is a *tool* which is used to expose materials to a hot environment. Ovens contain a hollow chamber and provide a means of heating the chamber in a controlled way.<sup>[1]</sup> In use since *antiquity*, they have been used to accomplish a wide variety of tasks requiring controlled heating.<sup>[2]</sup> Because they are used for a variety of purposes, there are many different types of ovens. These types differ depending on their intended purpose and based upon how they generate heat.

Ovens are often used for *cooking*, where they can be used to heat *food* to a desired *temperature*. Ovens are also used in the manufacturing of *ceramics* and *pottery*; these ovens are sometimes referred to as *kilns*. *Metallurgical furnaces* are ovens used in the manufacturing of *metals*, while *glass furnaces* are ovens used to produce *glass*.

There are many methods by which different types of ovens produce heat. Some ovens heat materials using the *combustion* of a *fuel*, such as *wood*, *coal*, or *natural gas*,<sup>[3]</sup> while many employ *electricity*. *Microwave ovens* heat materials by exposing them to *microwave radiation* while electric ovens and *electric furnaces* heat materials using *resistive heating*. Some ovens use *forced convection*, the movement of *gases* inside the heating chamber, to enhance the heating process, or, in some cases, to change the properties of the material being heated, such as in the *Bessemer*

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## Industrial oven

Article Talk

19, 1 language

Read Edit View history Tools

From Wikipedia, the free encyclopedia

This article needs additional citations for verification. Please help improve this article by adding citations to reliable sources. Unreliable material may be challenged and removed. (The message "Industrial oven" - user: "mehmetgul" - notice - 07:20 (February 2022) (view how and when to remove this message))

**Industrial ovens** are heated chambers used for a variety of industrial applications, including [curing](#), [cooking](#), or [baking](#) components, parts or final products. Industrial ovens can be used for large or small volume applications, in batches or continuously with a conveyor line, and a variety of temperature ranges, sizes and configurations.

Such ovens are used in many different applications, including chemical processing, food production, ovens in the electronics industry, where circuit boards are run through a conveyor belt to attach surface mount components.<sup>[1]</sup>

Other common types of industrial ovens include<sup>[2]</sup>

- Curing ovens** - Designed to cause a chemical reaction in a substrate once a specific temperature is reached. *Pre-dry coating* is one common curing oven use.
- Drying ovens** - Designed to remove moisture. Typical applications are pre-treating and painting. Such ovens are also sometimes known as *skins*, though they do not reach the same high temperatures as are used in *skins*.
- Baking ovens** - Combines the function of curing and drying ovens.
- Reflow Ovens** - A reflow oven is a machine used primarily for reflow soldering of surface mount electronic components to printed circuit boards (PCB). The oven contains multiple zones, which can be individually controlled for temperature. Generally, there are several heating zones followed by one or more cooling zones. The PCB moves through the oven on a conveyor belt, and is therefore subjected to a controlled temperature profile.
- Batch ovens** - Also called cabinet or *Walk-in/through ovens*, batch ovens allow for curing, drying or baking in small batches using wheeled racks, carts or trucks. Ovens such as this are often found in large volume businesses to allow batch-to-batch comparisons.
- Conveyor or Continuous Ovens** - Typically part of an automated conveyor processing line, conveyor ovens



Industrial convection oven used in the manufacture of aircraft components. Heating by gas-fired heat exchanger; fully automated control system holds an temperature within ±1%.



Industrial zero-fuel health check oven (left) and Sinter-Catcher.

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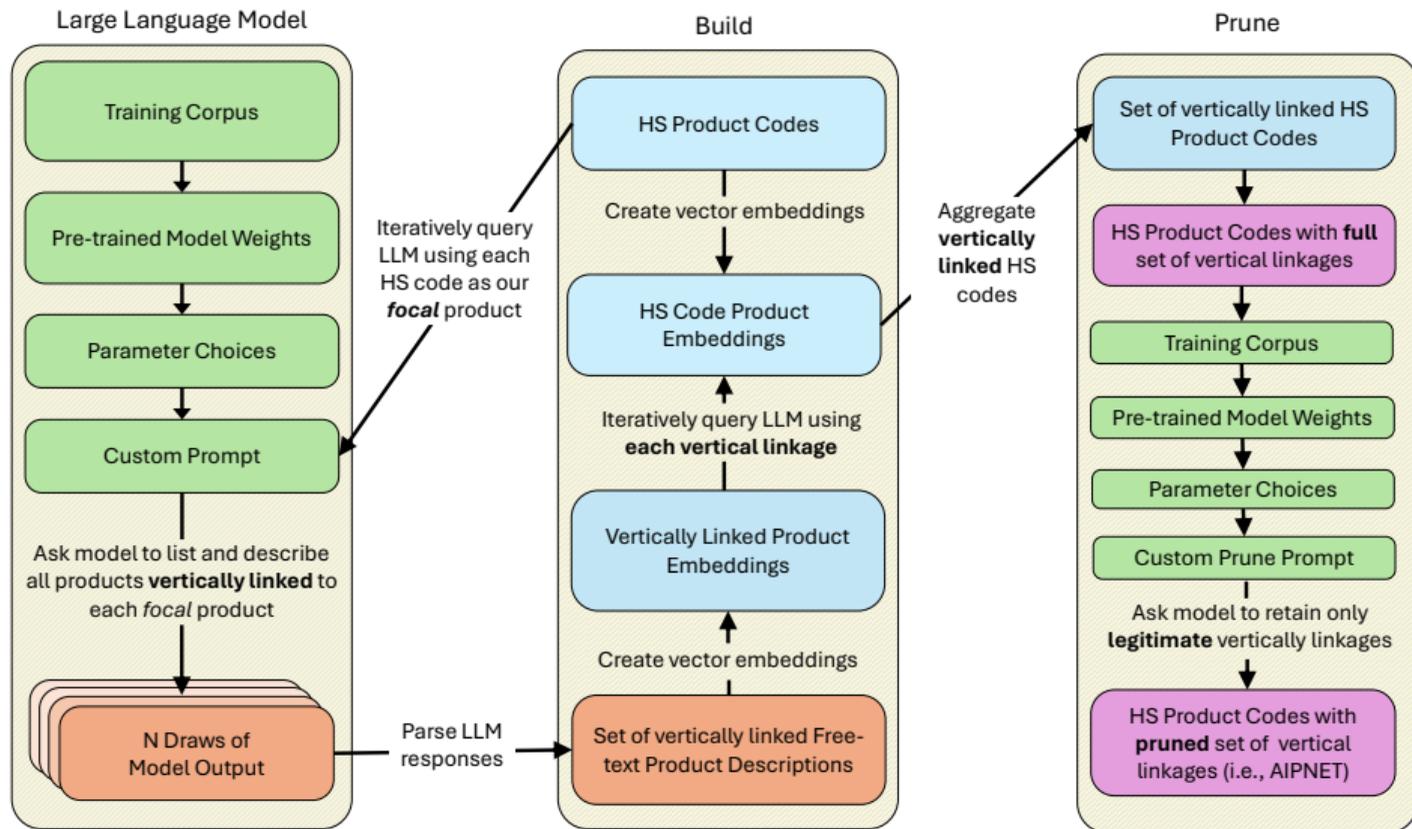
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# Beyond ChatGPT

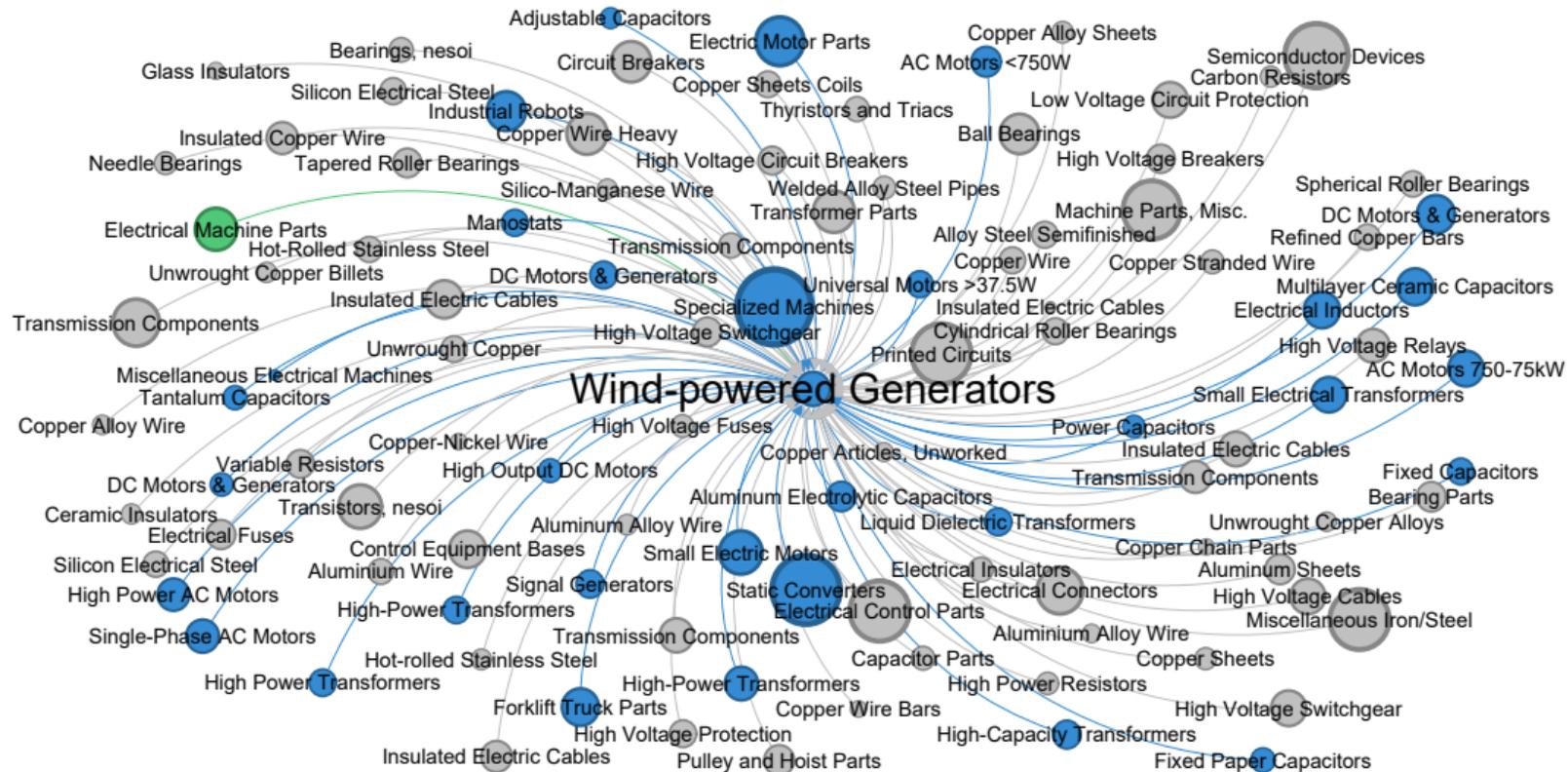
- ▶ Our LLM is trained on production process text
- ▶ Utilizes a refined prompting strategy for bootstrap learning
- ▶ Extracts structured output
- ▶ Iterative sampling
- ▶ Adversarial AI evaluations
- ▶ Match free-text responses to HS Code nomenclature

# AI pipeline to build AIPNET





# Building AIPNET II: Wind-powered Generators





# AI-built Production Network (AIPNET)



## Network Properties of AIPNET (HS6 Level)

<b>Property</b>	<b>HS6</b>	<b>HS4</b>
Number of Nodes	5,633	1,190
Number of Edges	980,018	48,212
Average Degree	347.96	81.03
Network Density	0.03	0.03
Global Clustering Coefficient	0.37	0.32
Assortativity	0.14	0.06
Number of Connected Components	1	1
Size of Largest Component	5,633	1,190

# Outline

Measurement

Validation

Global Patterns in Trade Data

Price Shocks and On-shoring

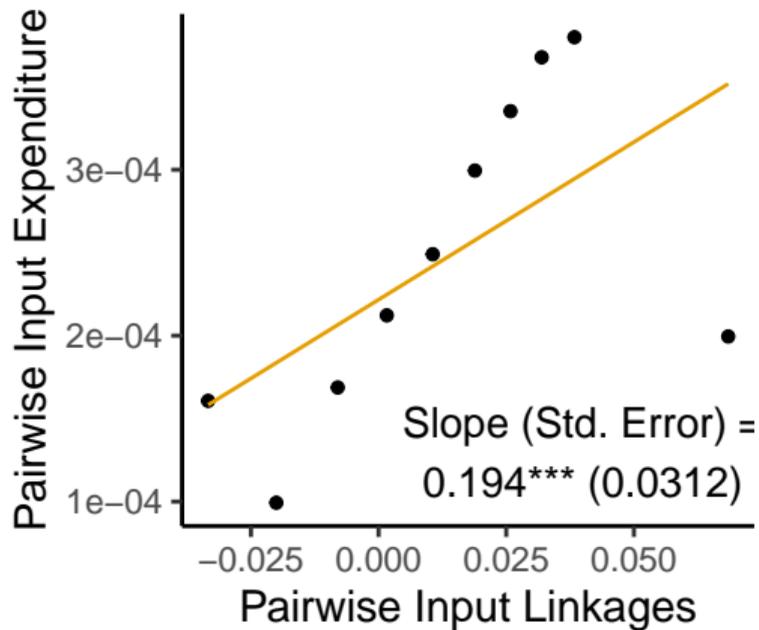
Onshoring Natural Experiment

# Validation

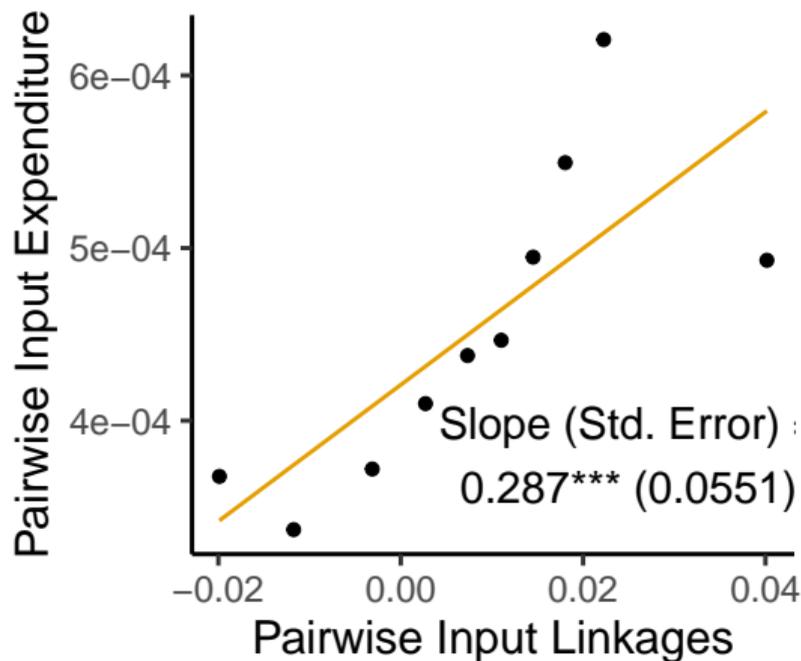
- ▶ Compare AIPNET to Input-Output Tables (IOTs)
  - ▶ Recast Product-level network into IOT structure
  - ▶ Compare Input-use intensity to AIPNET product linkages
- ▶ Compare to product-level supply chain position measures:
  - ▶ 'Upstreamness' (Fally, 2016; Antras et al. 2018)
  - ▶ Product Complexity 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

US

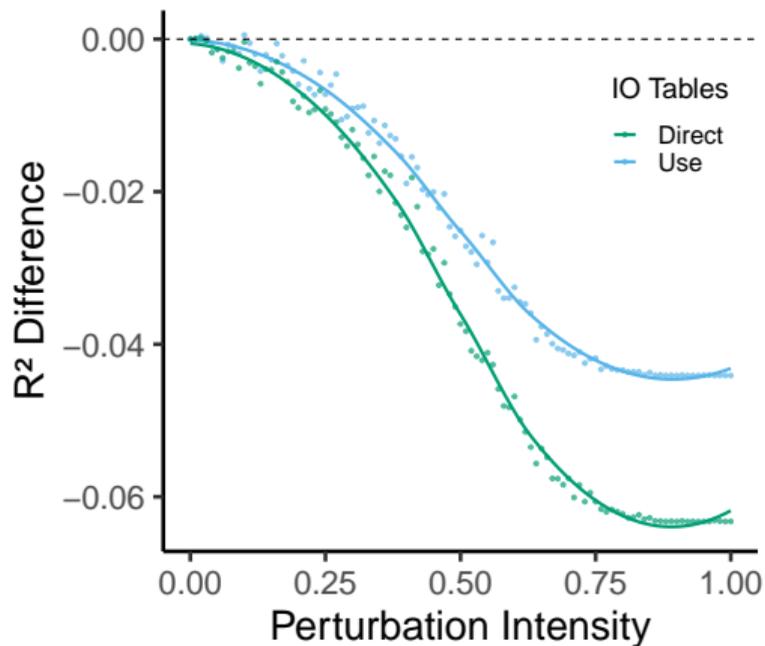


Mexico

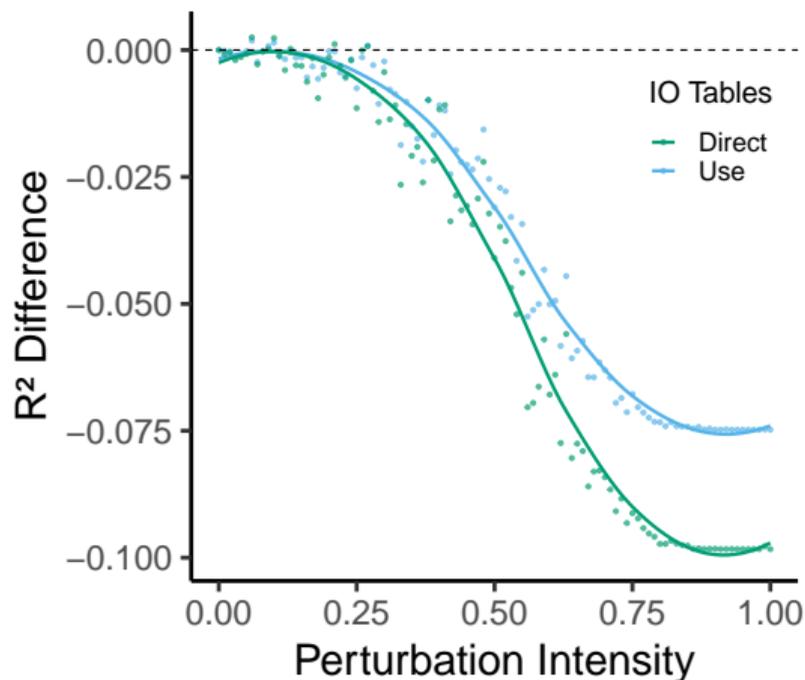


# Perturbing network attenuated validation estimates

US



Mexico



# 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

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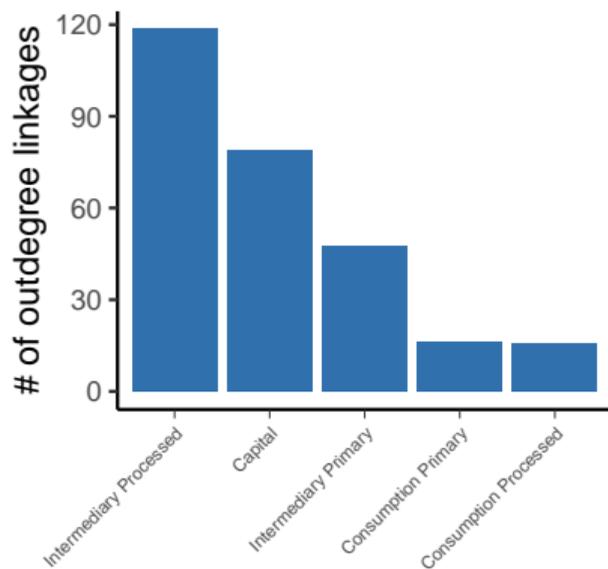
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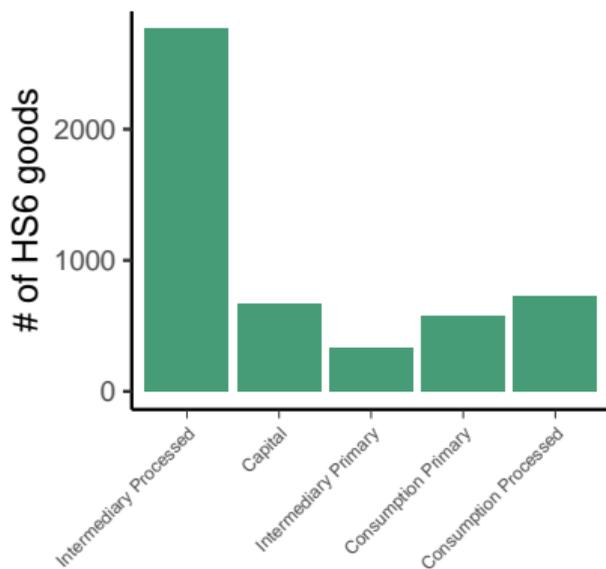
Onshoring Natural Experiment

# Relationship Between BEC Classification and Number of Output Uses for HS6 Goods

Output links by end-use type



# of HS6 goods by end-use type



# Integrating AIPNET with Topology of Global Trade Data

We develop a new measure of criticality or importance of an input that integrates trade data with AIPNET

- ▶ **A** provides the AIPNET adjacency matrix
- ▶  $TC_i$  trade concentration captures how much of the trade in a product is dominated by a few players or countries
- ▶  $GTS_i$  how much of the overall trade a product represents.

# Integrated Global Product Centrality (IGPC)

**IGPC:** Measures product importance in trade, extending PageRank algorithm.

$$\mathbf{X} = (1 - d)\mathbf{B} + d\mathbf{A}\mathbf{W}\mathbf{X}$$

**X:** IGPC scores,  $d$ : damping factor, **B:** base importance, **A:** adjacency matrix (AIPNET), **W:** weight matrix

Base importance:

$$B_i = TC_i^\alpha \times GTS_i^\beta$$

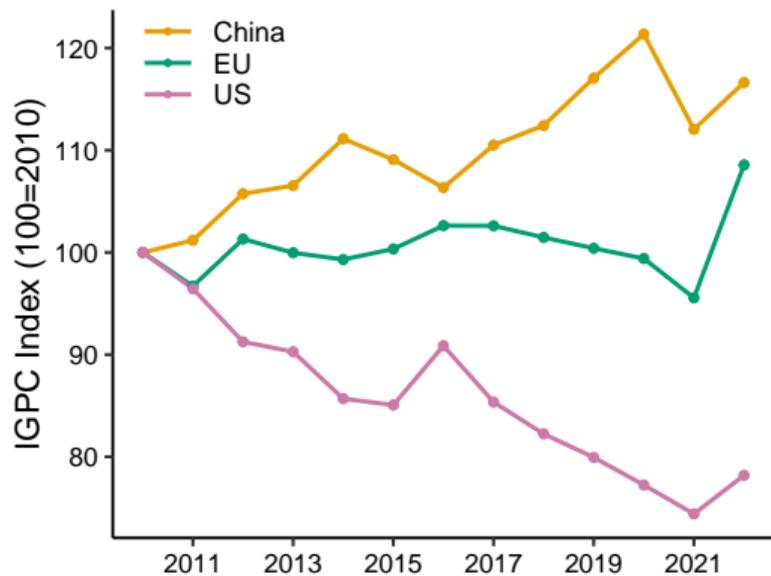
Weight matrix:

$$W_{ij} = GTS_i^\gamma$$

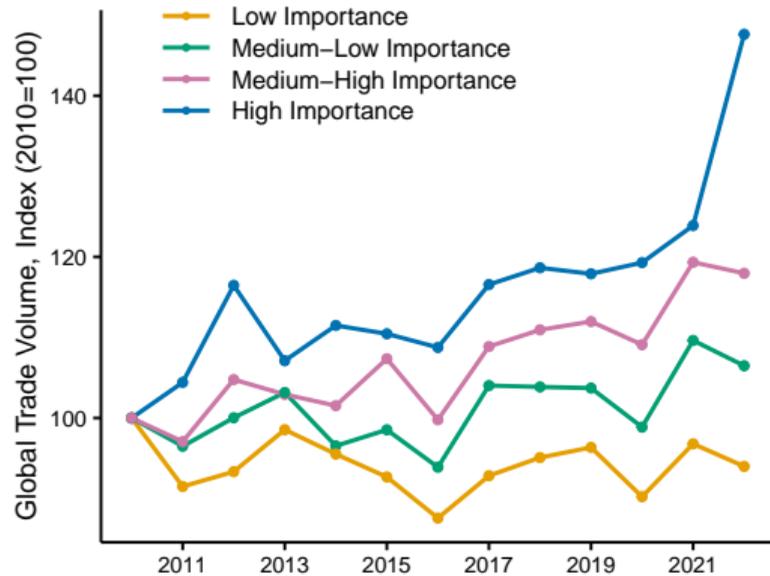
where  $TC$ : Trade Concentration,  $GTS$ : Global Trade Share, and  $\alpha, \beta, \gamma$ : weighting parameters.

# Diverging trends in IGPC weighted imports across countries and product centrality levels

## Within country trends (raw data)

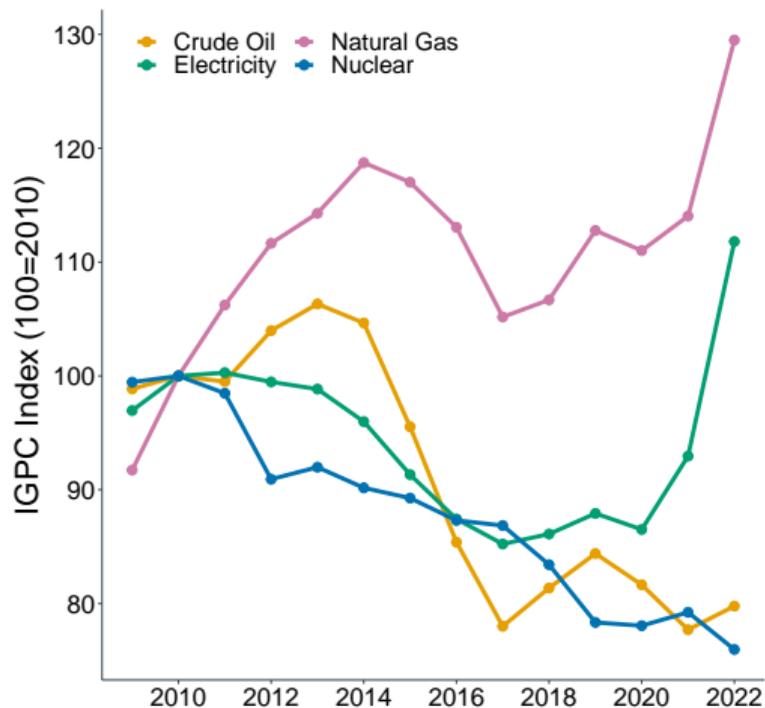


## Between product trends (raw data)

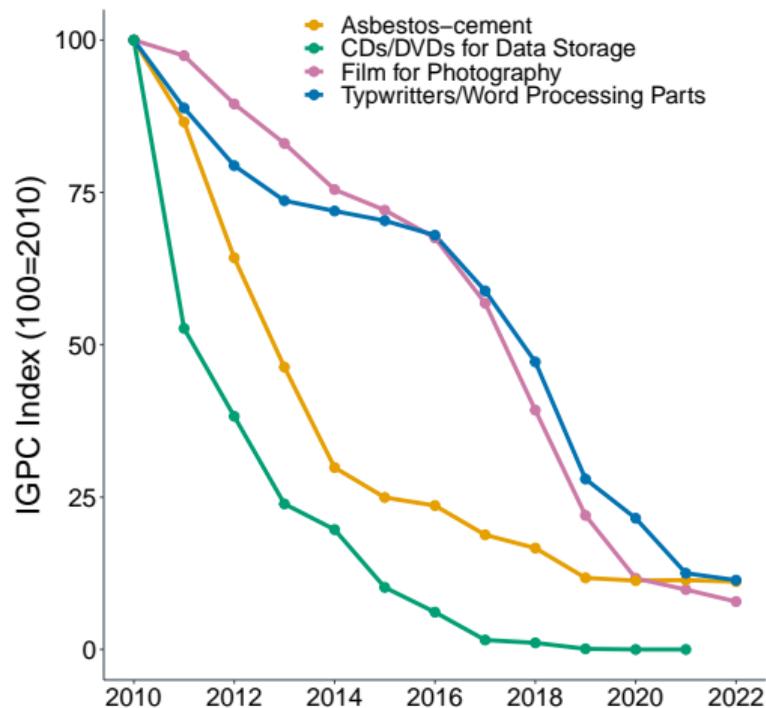


# Changes in Product Importance in Global Supply Chains

## Energy Products

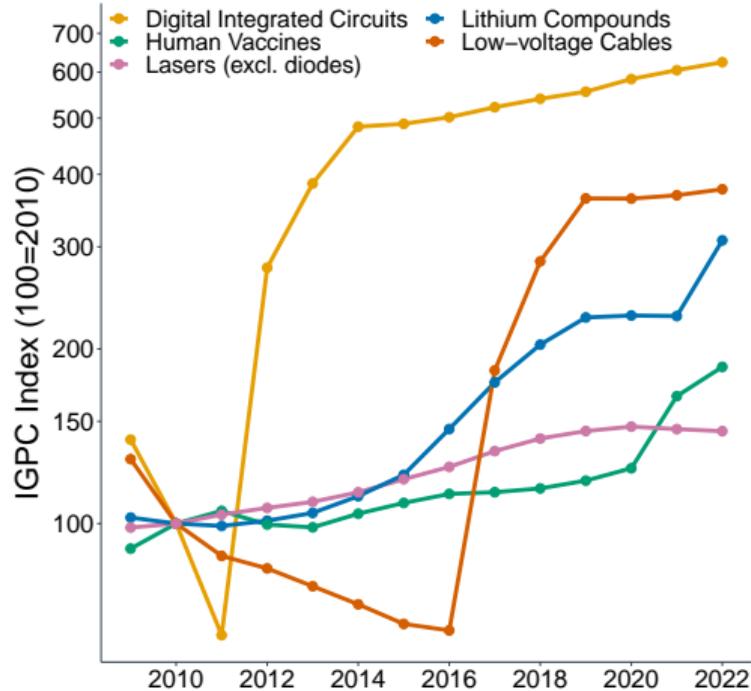


## Declining Products

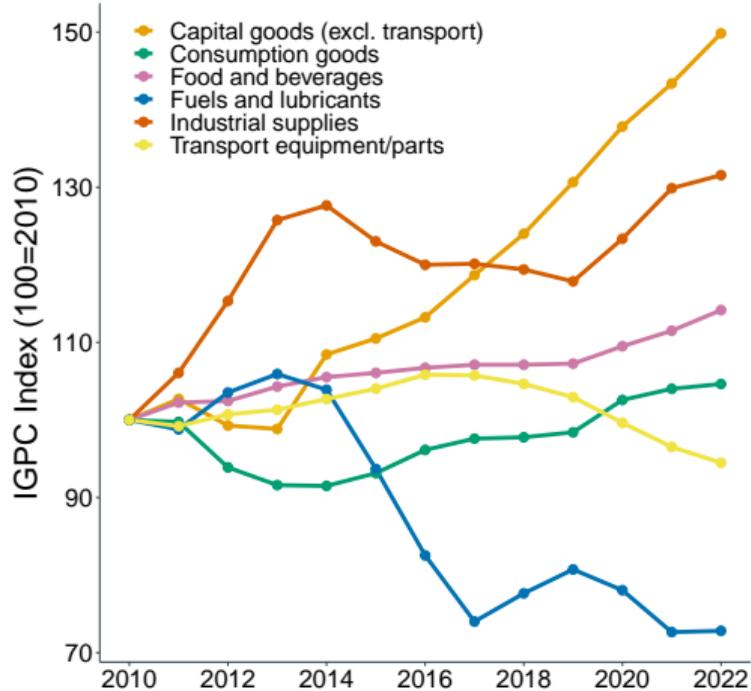


# Changes in Product Importance in Global Supply Chains

## Emerging Products

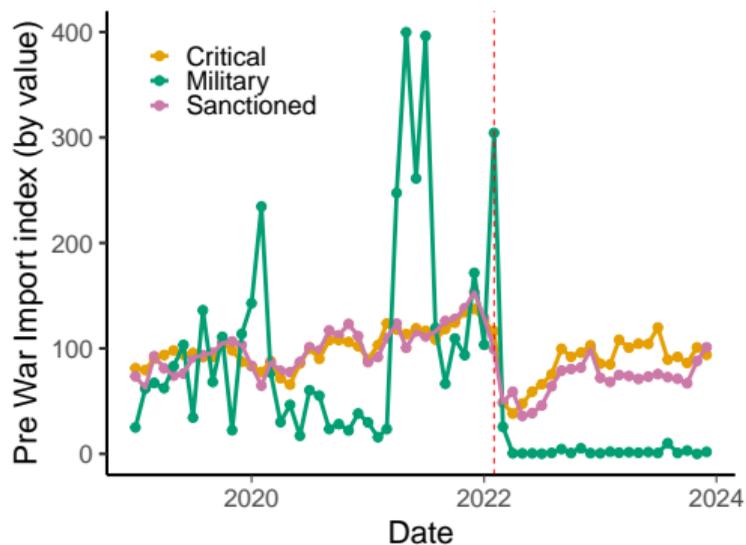


## Broad Economics Categories

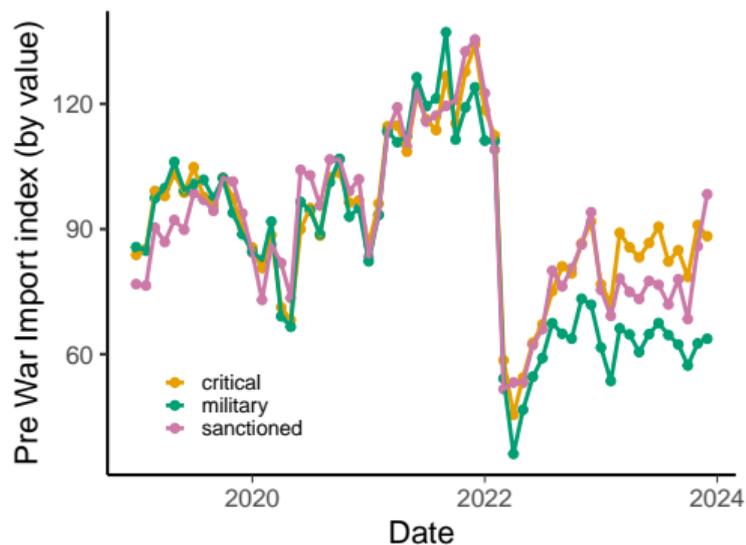


# Import volume index for **Sanctioned goods trade with Russia**, as seen through AIPNET linkages

## Final use goods

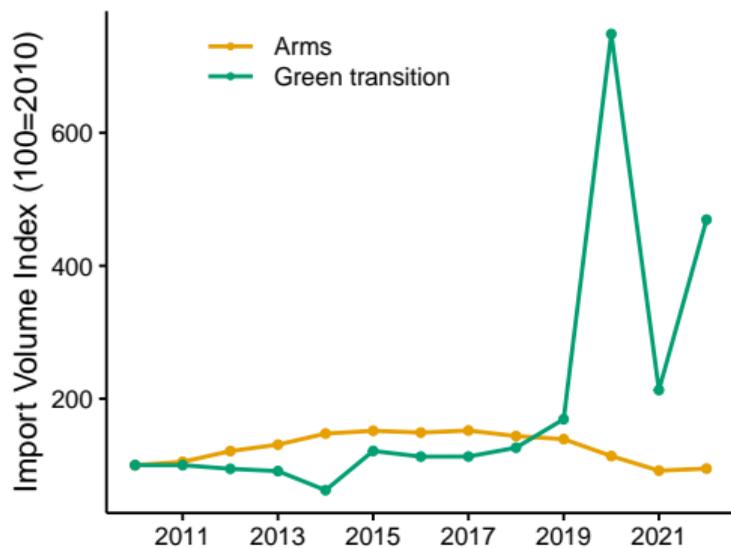


## AIPNET linked inputs



# Import volume index for **Climate action and arms trade**, as seen through AIPNET linkages

## Final use goods



## AIPNET linked inputs



# Outline

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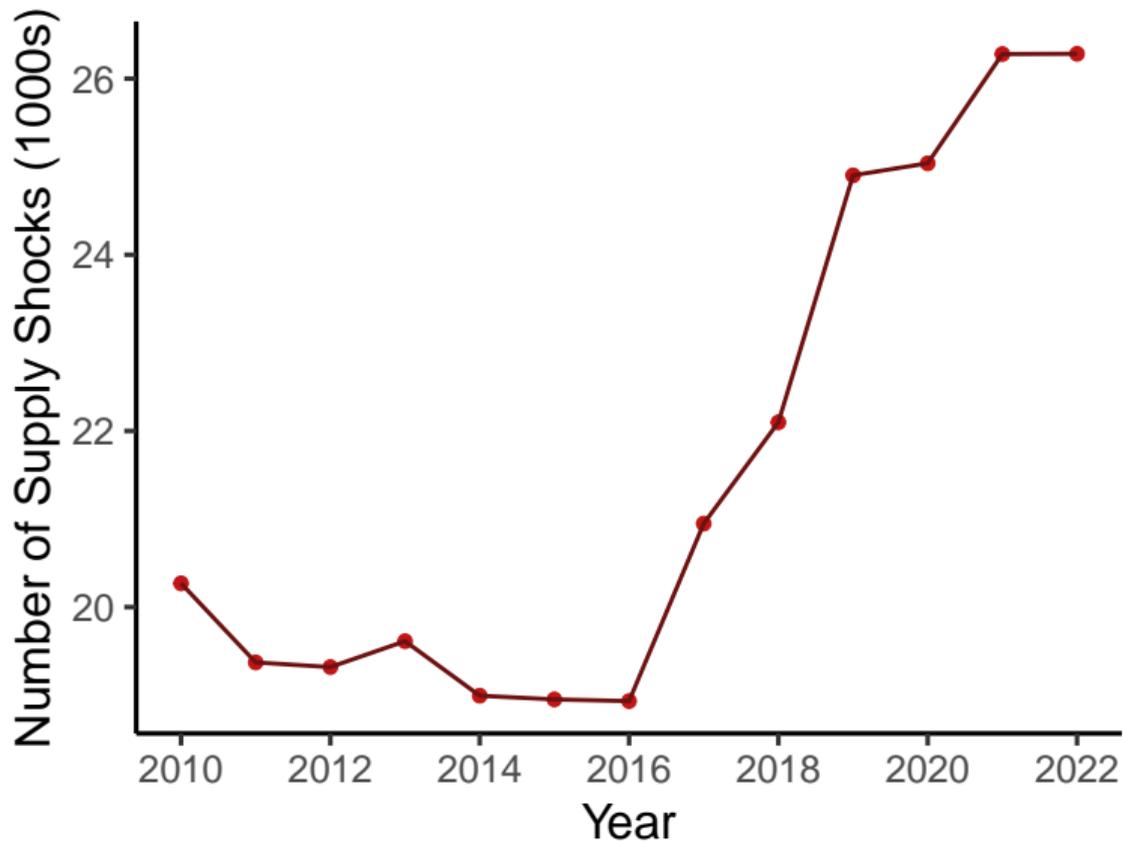
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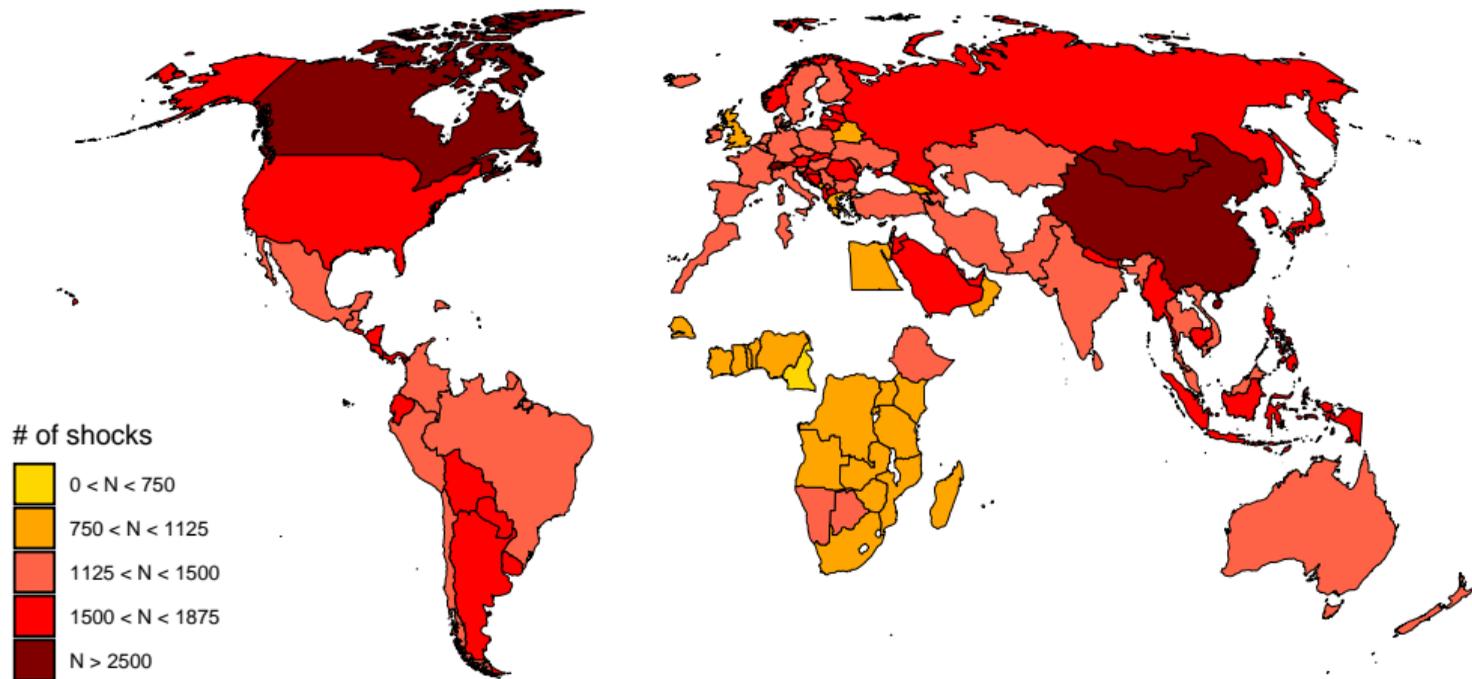
Price Shocks and On-shoring

Onshoring Natural Experiment

## 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

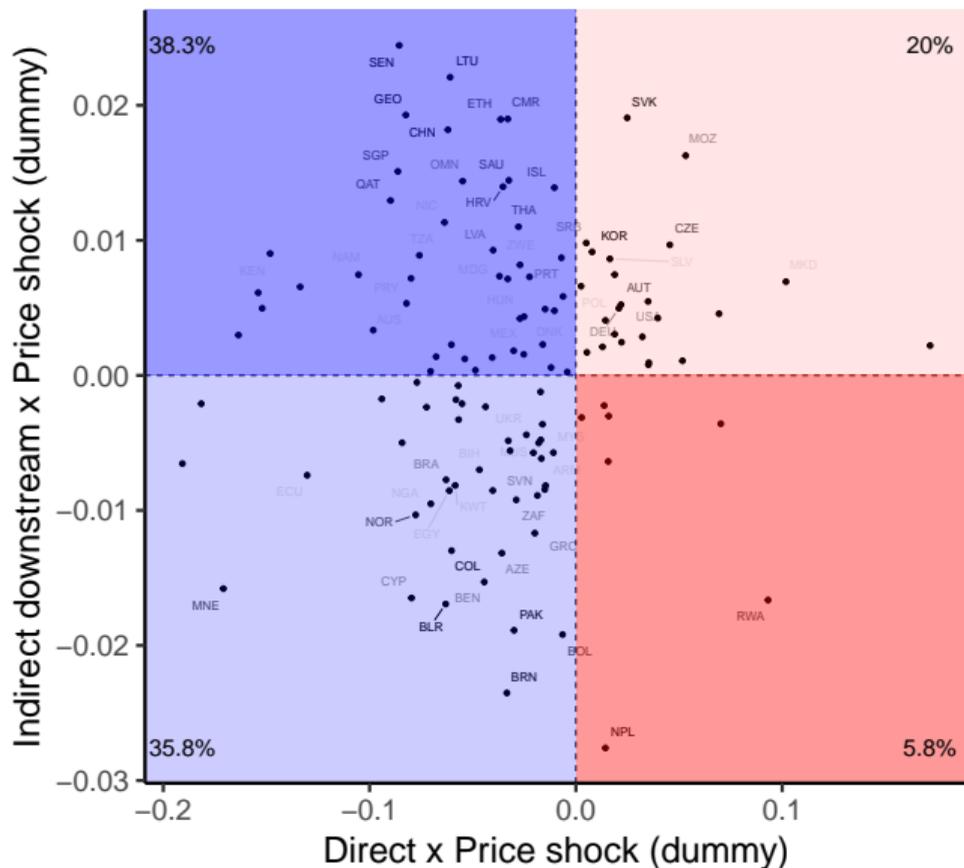
$$\ln(\text{Import}_{ict}) = \beta_1(S_{ict} \times W_{ij}) + \beta_2(S_{jct} \times W_{ij}) + \alpha_{ijc} + \gamma_{jtc} + \epsilon_{ijt}$$

# Direct and Indirect Supply Shocks

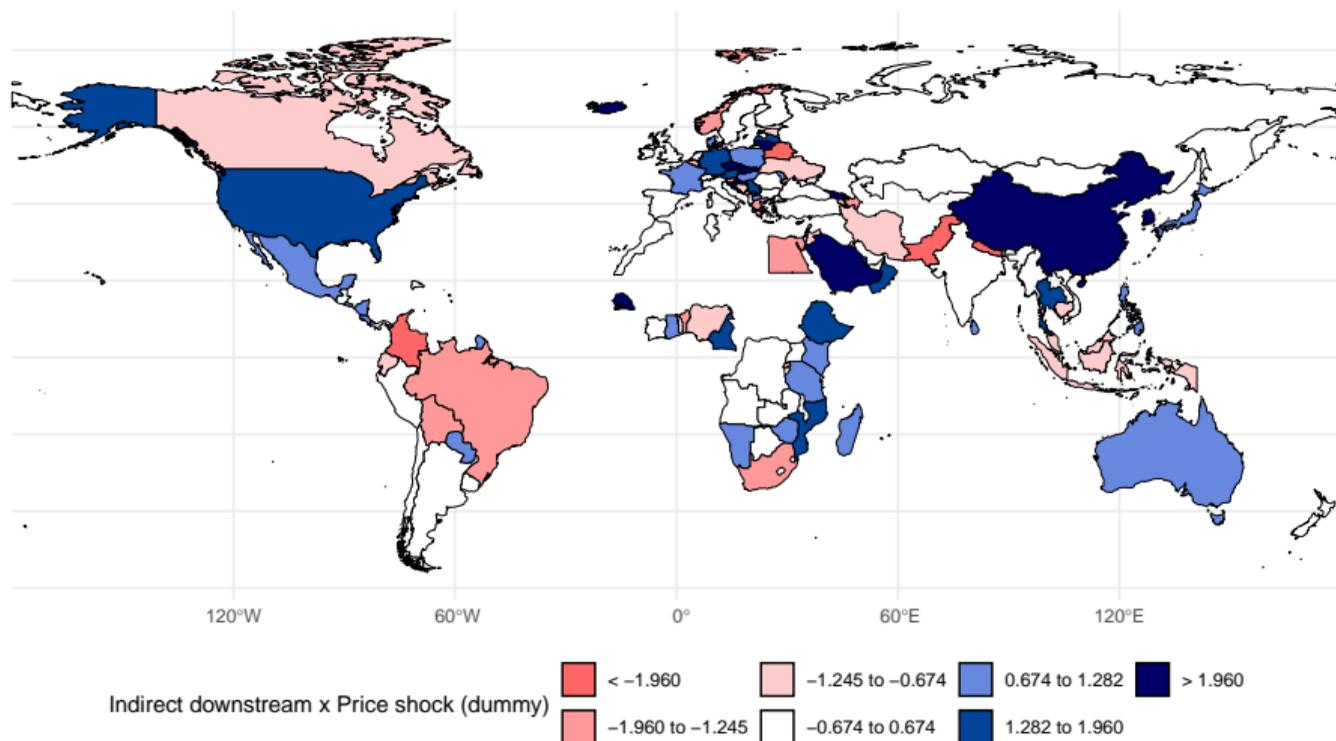
<i>Dependent variable:</i>	log(Import Value)
AIPNET $\times$ Indirect upstream price shock (dummy)	1.4*** (0.0004)
AIPNET $\times$ Direct own price shock (dummy)	-2.3*** (0.0046)
R <sup>2</sup>	0.952
Observations	1.73B

**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



# On-shoring estimate by country estimate this by country



# Outline

Measurement

Validation

Global Patterns in Trade Data

Price Shocks and On-shoring

Onshoring Natural Experiment

# 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

# Example of Good that was localized

Capital equipment

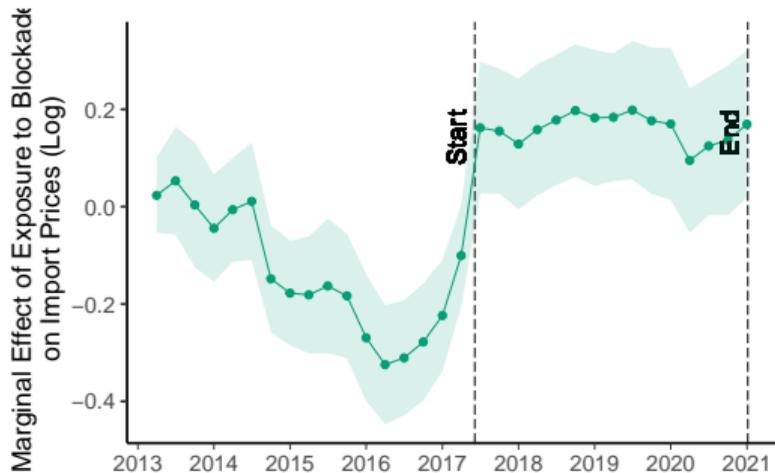


Capital equipment

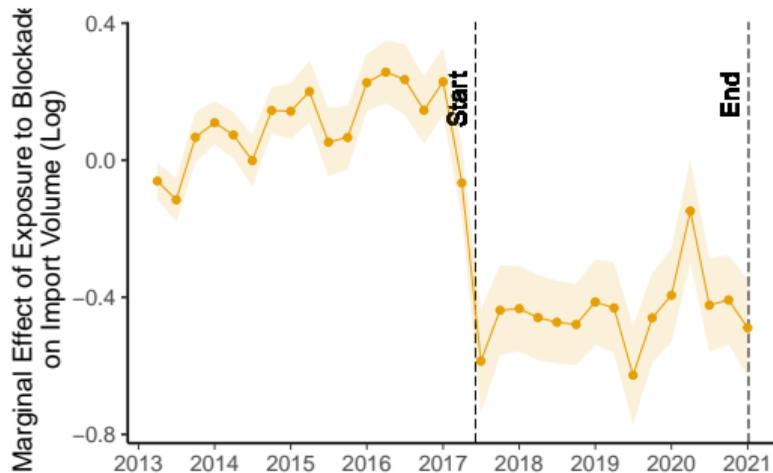


# Blockade Dramatically Shifted Trade Flows

## Import Prices

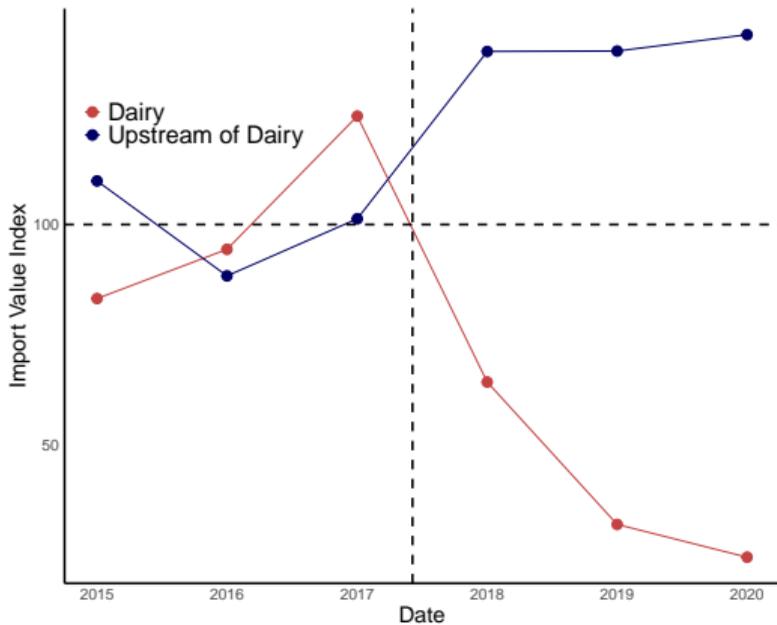


## Import Volume

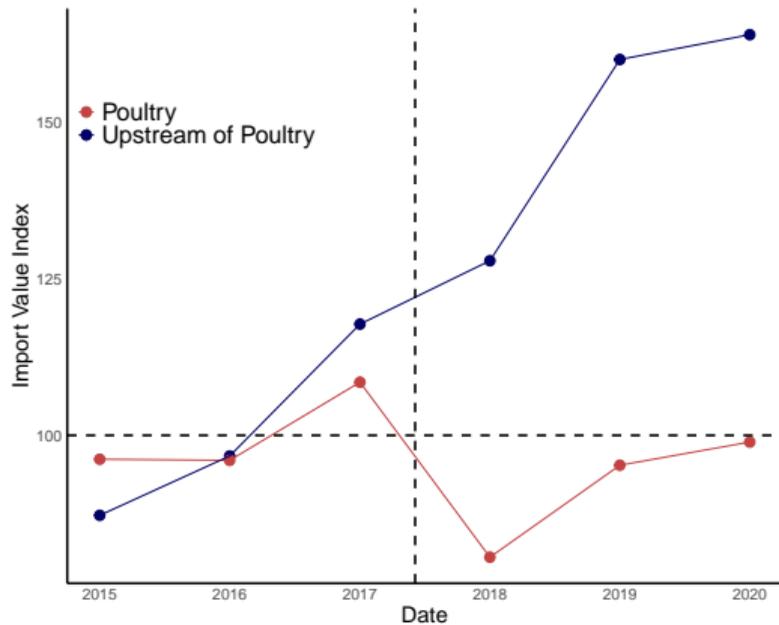


# Examples of onshoring evidence measured through AIPNET linkages in Qatar case

## Dairy



## Poultry



# Unpacking the Import Equation

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

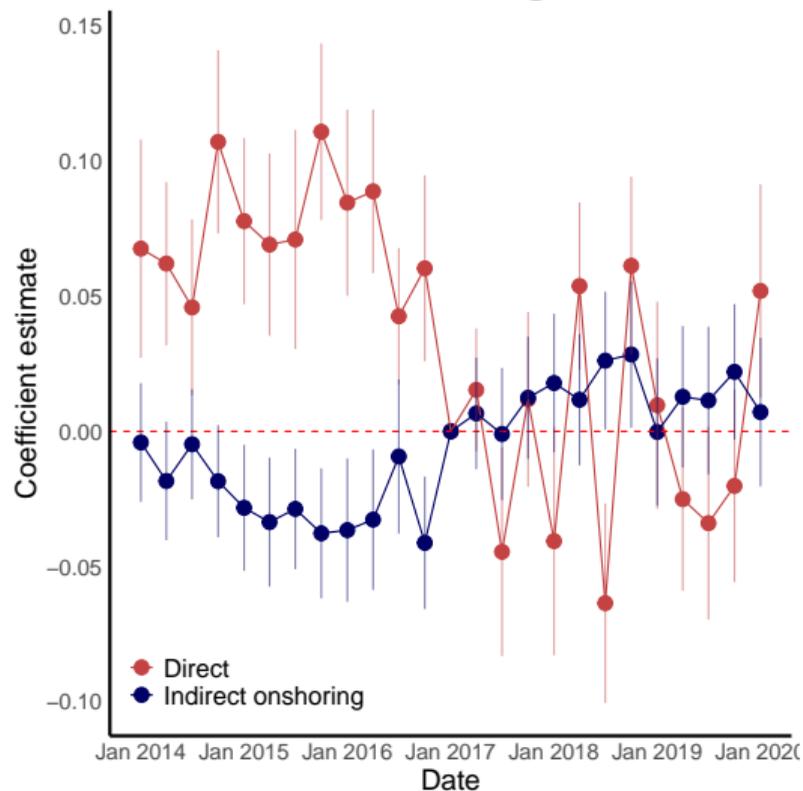
- ▶  $E_i$ : Exposure of product  $i$  to blockade based on pre-blockade import share
- ▶  $W_{ij}$ : Dummy for whether  $i$  is used as an input to produce  $j$
- ▶  $\beta_1$ : Direct effect of blockade exposure
- ▶  $\beta_2$ : Indirect effect of blockage exposure

# Pooled Onshoring Regression for Qatar

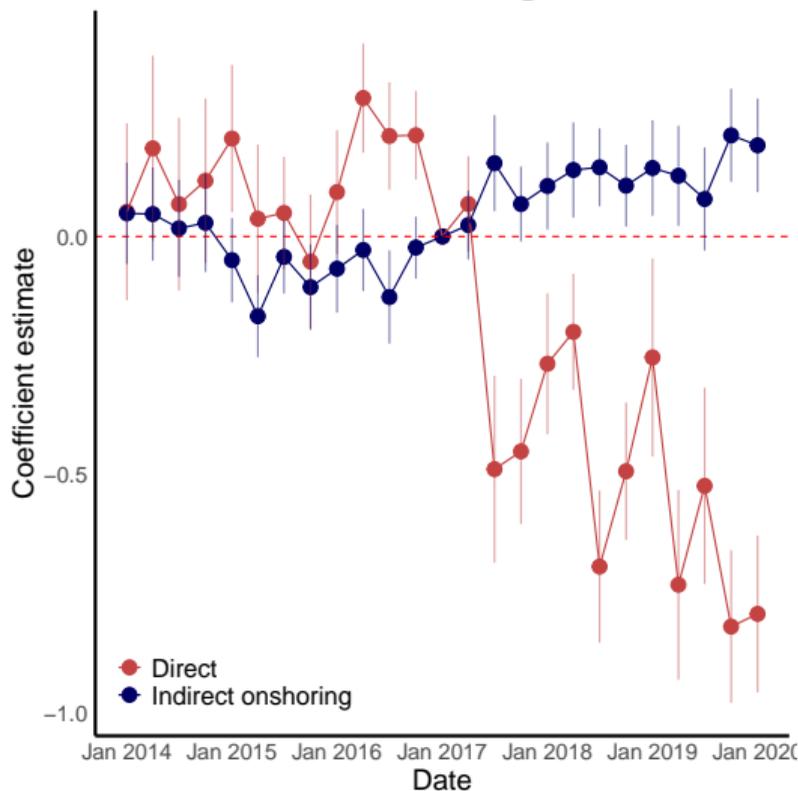
	(1)	(2)	(3)	(4)	(5)	(6)
<i>Dependent variable</i>	upstream good import > 0			log(upstream good import)		
<i>Panel A: HS4 x quarterly panel</i>						
Blockade × Direct Exposure	-0.0685*** (0.0120)		-0.0755*** (0.0142)	-0.5595*** (0.0718)		-0.5809*** (0.0718)
Blockade × Downstream Exposure		0.0267*** (0.0084)	0.0286*** (0.0075)		0.0881** (0.0409)	0.1616*** (0.0430)
R <sup>2</sup>	0.66689	0.66701	0.66743	0.86734	0.86695	0.86815
Observations	991,150	976,650	976,650	787,950	776,058	776,058
<i>Panel B: HS6 x quarterly panel</i>						
Blockade × Direct Exposure	-0.0297** (0.0120)		-0.0379*** (0.0126)	-0.4081*** (0.0521)		-0.4154*** (0.0531)
Blockade × Downstream Exposure		0.0138* (0.0073)	0.0082 (0.0106)		0.0204 (0.0370)	0.0605 (0.0380)
R <sup>2</sup>	0.56880	0.56778	0.55651	0.78021	0.77878	0.77958
Observations	9,640,300	9,405,825	9,405,825	5,833,222	5,699,916	5,699,916
Dyad FE	X	X	X	X	X	X
Time FE	X	X	X	X	X	X

# Event-study style regression with flexible timing

## Extensive margin



## Intensive margin



# 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 (this week!)

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