Supply Chain Disruption and Reorganization: Theory and Evidence from Ukraine's War

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Motivation

- Production (supply chain) networks are crucial for firms' & regions' economic activity
- Production networks transmit negative shocks throughout the economy
  - Transient shocks, such as natural disasters
  - Intense and prolonged shocks, such as wars or conflicts example
- Shocks may also alter the structure of production networks
  - Mitigation: substitution of supplier or buyer linkages
  - Amplification: scale down production, and stop trading with existing partners

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- Annexation of Crimea, and intense but localized conflict in the Donbas region

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  - $\downarrow$ relative output ($\approx 20\%$) with positive prior supplier/buyer linkages to conflict areas
  - Reorganization of linkages *strictly outside conflict areas*
    - $\uparrow$ supplier linkages with a higher supplier exposure (substitution)
    - $\downarrow$ supplier linkages with a higher buyer exposure (scale down)
    - $\downarrow$ buyer linkages with higher supplier (and buyer) exposures

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    - $\downarrow$ buyer linkages with higher supplier (and buyer) exposures
- Multi-sector & region GE model:
  - Sufficient statistics for firm sales given *observed* reorganization of production networks
  - Validate model-predicted sales; reject model without network reorganization
  - $\downarrow$ 9% aggregate welfare strictly outside conflict areas
    - Network reorganization has large but offsetting effects on aggregate welfare

Contributions to the Literature

- Disruption of production networks: Barrot & Sauvagnat '16; Boehm, Flaaen, Pandalai-Nayar '19; Carvalho, Nirei, Saito, Tahbaz-Salehi '21; Khanna, Morales, Pandalai-Nayar '22; ...

  ⇒ Direct evidence and quantification of disruption *and reorganization* of production networks

- Theory of endogenous prod network formation: Antras, Fort, Tintelnot '16; Oberfield '18; Lim '18; Bernard, Moxnes, Saito '19; Eaton, Kortum, Kramarz '22; Arkolakis, Huneeus, Miyauchi '23; Dhyne, Kikkawa, Kong, Mogstad, Tintelnot '22; Baqaee, Burstein, Duprez, Farhi '23; ...

  ⇒ Framework to assess how *observed* production network changes affect production and welfare without relying on a particular microfoundation

- Economic costs of war: Guidolin & La Ferrara '07; Hjort '14; Amodio & Di Maio '18; Rohner & Thoenig '21; Ksoll, Macchiavello, Morjaria '22; Korovkin & Makarin '23; Couttenier, Monnet, and Piemontese '22; ...

  ⇒ Large economy-wide propagation effects of localized conflicts

Outline

Background and Data

Background: 2014 Russia-Ukraine War

- In February 2014, right after Ukrainian revolution, Russia annexed Crimea and started supporting Donbas separatists
- Sudden, intense, and localized conflict in Donbas regions (until February 2022)
- Donbas (and Crimea) were economic centers of Ukraine before the war
  - Donbas: extractive industry (coal), metallurgy, manufacturing
  - Crimea: agriculture, tourism, some industry
  - Jointly covered 17.5% of Ukraine's 2013 GDP

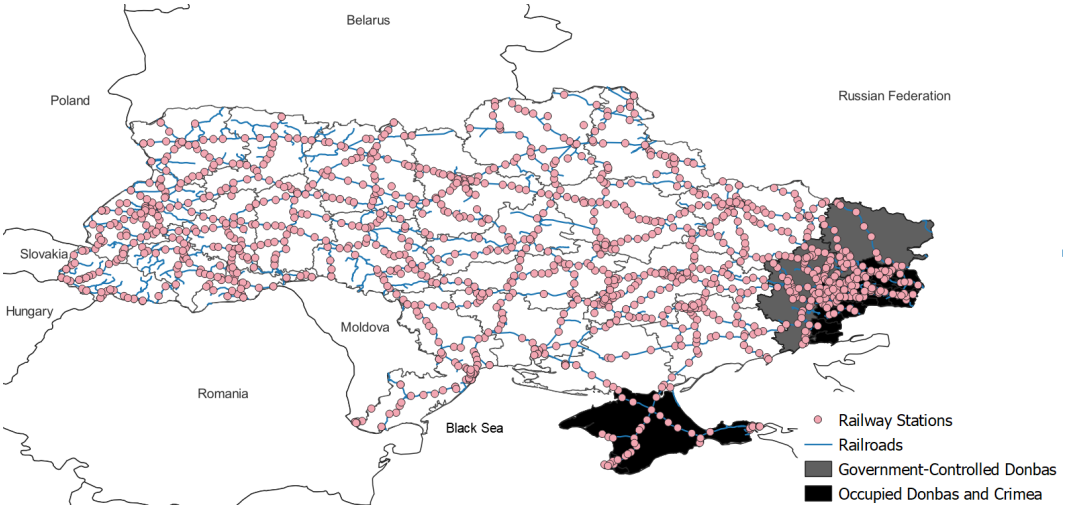
Data

- Universe of firm-to-firm railroad shipments within Ukraine, 2012–2016
  - $\sim$100 mln transactions between $\sim$8.5 k firms
  - Sender and receiver firm IDs, dates, weights (kg), freight charges, product codes, origin & destination station codes
  - Focus on inter-firm trade ($\sim$ 94% of transactions)
  - Impute transaction value using product code (using separate customs data)

- Focusing on railway shipment (vs other shipment modes) unlikely to bias results
  - Railways penetrate all regions in Ukraine, covering 80% of freight in ton-km (Ukr Stat '18)
  - Time-invariant firm-level factors in mode choice drop out in diff-in-diff design

- Accounting data for Ukrainian firms, 2010–2018
  - Sources: Spark-Interfax, ORBIS/AMADEUS

Ukrainian Railroads with Stations

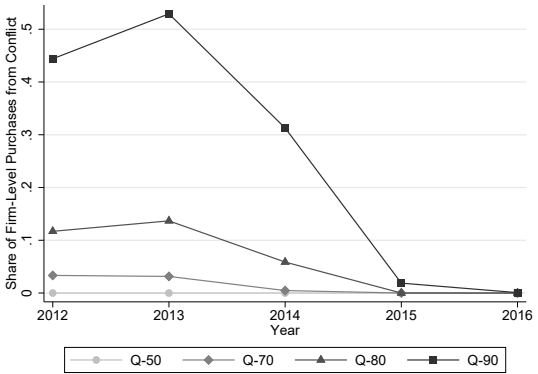


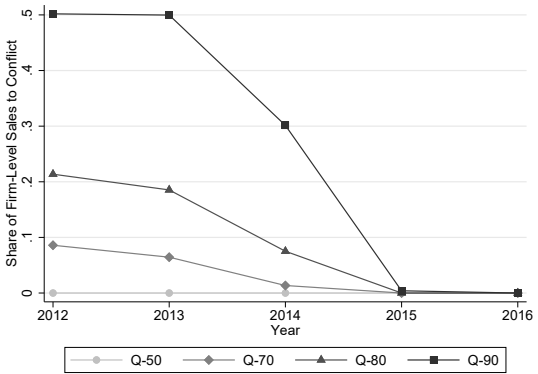
Define "conflict areas" as Crimea and DPR/LPR in Donbas Region hereinafter

Reduced-Form Evidence

Sudden and Large Drop of Trade from & to Conflict Areas

- Weighted fraction of suppliers (left) and buyers (right) from/to conflict areas by firms outside direct conflict areas





event-study | output loss in conflict areas | trade exposure to Russia

Firm-Level Impacts of Conflict Exposure

Difference-in-differences specification:

$$Y_{ft} = \gamma \times Post_t \times \text{SupplierExposure}_f + \beta \times Post_t \times \text{BuyerExposure}_f + \alpha_f + \delta_t + \varepsilon_{ft}$$

- f: firms outside conflict areas
- Y_{ft}: sales, linkages outside conflict areas
- $\text{SupplierExposure}_f$: Value share of shipment *from* conflict areas in 2012-13
- BuyerExposure_f: Value share of shipment *to* conflict areas in 2012-13

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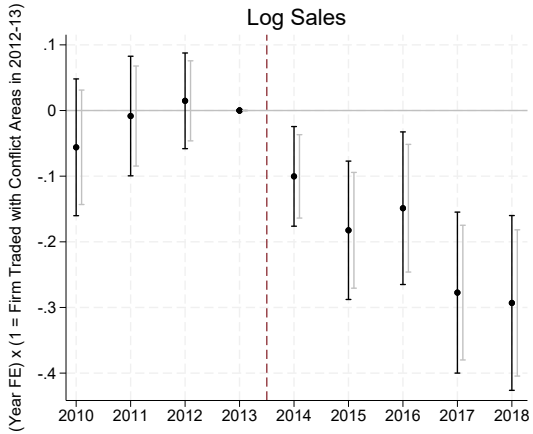
Identification concerns:

1. Parallel trends / non-random exposure?
   $\Rightarrow$ Sudden unanticipated shocks & no pretrends, recentering (Borusyak-Hull '23)
2. Other exposures to conflict? (e.g., migration, military demand, trade with Russia)
   $\Rightarrow$ Robust to controlling for region-time FE, industry-time FE, and trade with Russia

Large Negative Impacts of Conflict Exposure on Sales

$$\log Sales_{ft} = \gamma_t \times \mathbb{1}[\text{TradeConflictExposure}_f > 0] + \alpha_f + \delta_t + \varepsilon_{ft}$$



90% CI (in black) and 95% CI (in gray)

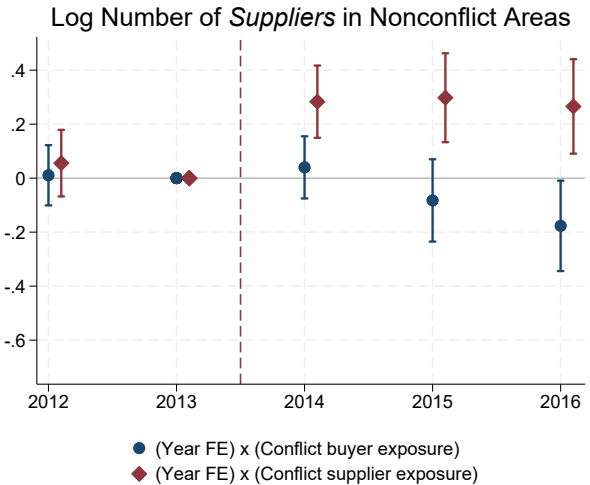
Impacts of Supplier and Buyer Conflict Exposures on Sales

	(1) Log Sales	(2) Log Sales	(3) Log Sales
Post-2014 × 𝟙[Firm traded with conflict areas, 2012–13]	-0.183***		
	(0.046)		
Post-2014 × Firm's buyer conflict exposure, 2012–13		-0.265**	
		(0.109)	
Post-2014 × Firm's supplier conflict exposure, 2012–13		-0.316***	
		(0.103)	
Post-2014 × 𝟙[High firm's buyer conflict exposure, 2012–13]			-0.197***
			(0.069)
Post-2014 × 𝟙[High firm's supplier conflict exposure, 2012–13]			-0.167**
			(0.066)
Firm FE	✓	✓	✓
Year FE	✓	✓	✓
Mean	16.890	16.890	16.890
SD	2.484	2.484	2.484
Observations	35,029	35,029	35,029
Number of Firms	4,802	4,802	4,802

impacts on sales not reported robustness

Reorganization of Supplier Linkages Outside Conflict Areas

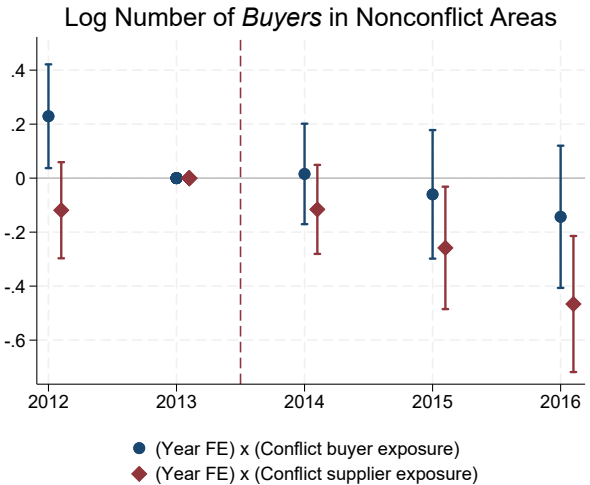
$$Y_{ft} = \gamma_t \times \text{SupplierExposure}_f + \beta_t \times \text{BuyerExposure}_f + \alpha_f + \delta_t + \varepsilon_{ft}$$



- Supplier exposure ↑ suppliers outside conflict areas: substitution
- Buyer exposure ↓ suppliers outside conflict areas: scale down production

Reorganization of Buyer Linkages Outside Conflict Areas

$$Y_{ft} = \gamma_t \times \text{SupplierExposure}_f + \beta_t \times \text{BuyerExposure}_f + \alpha_f + \delta_t + \varepsilon_{ft}$$



- Supplier exposure (& buyer exposure) ↓ buyers outside conflict areas

Impacts of Supplier and Buyer Conflict Exposures on Linkages

	(1) Log # of Suppliers in Nonconflict Areas	(2) Log # of Buyers in Nonconflict Areas	(3) Log # of Suppliers in Nonconflict Areas	(4) Log # of Buyers in Nonconflict Areas
Post-2014 × Firm's buyer conflict exposure, 2012–13	-0.099	-0.192**		
	(0.062)	(0.097)		
Post-2014 × Firm's supplier conflict exposure, 2012–13	0.245***	-0.199**		
	(0.066)	(0.095)		
Post-2014 × $\mathbb{1}$[High firm's buyer conflict exposure, 2012–13]			-0.060	-0.132***
			(0.037)	(0.046)
Post-2014 × $\mathbb{1}$[High firm's supplier conflict exposure, 2012–13]			0.103***	-0.106**
			(0.037)	(0.051)
Firm FE	✓	✓	✓	✓
Year FE	✓	✓	✓	✓
Mean	1.755	1.916	1.755	1.916
SD	1.247	1.488	1.247	1.488
Observations	20,628	13,410	20,628	13,410
Number of Firms	4,983	3,600	4,983	3,600

Taking Stock

- $\downarrow$ relative output ($\approx$ 20%) with higher supplier and buyer exposures
- Reorganization of linkages *strictly outside conflict areas*
  - $\uparrow$ supplier linkages with a higher supplier exposure
  - $\downarrow$ supplier linkages with a higher buyer exposure
  - $\downarrow$ buyer linkages with higher supplier (and buyer) exposures

Model

Environment

- Regions: $i \in \mathcal{L}$
- Measure L_i of HHs in region i; supply labor inelastically at competitive wages w_i
- Continuum of firms producing differentiated tradable intermediate goods
- Heterogeneous firm types in region i: $\omega \in \Omega_i$, measure N_i
  - e.g., heterogeneity in prior connection to conflict areas
- Competitive local retailers combine aggregate final goods from local firms
- Single sector for presentation; extend to multiple sector later

Technology: Intermediate Goods Producers ("Firms")

- Firm type $\omega \in \Omega_i$'s production technology: CD-CES

$$Y_i(\omega) = Z_i(\omega) \left(\frac{L_i(\omega)}{\beta_L} \right)^{\beta_L} \left(\frac{Q_i(\omega)}{\beta} \right)^{\beta}$$

  where $\beta + \beta_L = 1$

- $Q_i(\omega)$ is the intermediate input bundle, given by

$$Q_i(\omega) = \left(\sum_{u \in \mathcal{L}} \sum_{v \in \Omega_u} M_{ui}(v, \omega) q_{ui}(v, \omega)^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}}$$

  - $M_{ui}(v, \omega)$: measure of supplier linkages from $\Omega_u(v)$ to $\Omega_i(\omega)$
  - $M_{ui}(v, \omega)$ can be endogeneous, but no need to specify its rule
    - We derive how firm sales and welfare respond given *observed* changes in $M_{ui}(v, \omega)$

Technology: Retailers

- Competitive retailers access all intermediate inputs produced in region i

$$Y_i^F = \left(\sum_{\omega \in \Omega_i} N_i(\omega) q_{i,k}^F(\omega)^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}}$$

- HHs consume with linear utility $u(Y_i^F) = Y_i^F$

Trade Costs, Market Structure, and Prices

- Under monopolistic comp. with CES demand & continuum of suppliers, price of suppliers $\omega \in \Omega_i$ to buyers $\upsilon \in \Omega_d$ follows

$$p_{id}(\omega, \psi) = \frac{\sigma}{\sigma - 1} C_i(\omega) \tau_{id}(\omega, \psi),$$

  - $\tau_{id}(\omega, \psi)$: iceberg trade costs

- Marginal cost of production:

$$C_i(\omega) = \frac{1}{Z_i(\omega)} w_i^{\beta_L} P_i(\omega)^{\beta},$$

$$P_i(\omega) = \left(\sum_{u \in \mathcal{L}} \sum_{\upsilon \in \Omega_u} M_{ui}(\upsilon, \omega) p_{ui}(\upsilon, \omega)^{1-\sigma} \right)^{\frac{1}{1-\sigma}}$$

Trade Flows and General Equilibrium

- Nominal trade flow from suppliers $\upsilon \in \Omega_u$ to buyers $\omega \in \Omega_i$:

$$X_{ui}(\upsilon, \omega) = M_{ui}(\upsilon, \omega)\tau_{ui}(\upsilon, \omega)^{1-\sigma} C_u(\upsilon)^{1-\sigma} D_i(\omega),$$

- Labor market & intermediate goods market clears detail

- Resident's income (wage & firm profit)

$$E_i = w_i + \frac{1}{L_i} \sum_{\omega \in \Omega_i} \pi_i(\omega)$$

- Resident's welfare (real income):

$$\mathcal{W}_i = \frac{E_i}{P_i^F}, \quad P_i^F = \left(\sum_{\omega \in \Omega_i} \varsigma N_i(\omega) \, C_i(\omega)^{1-\sigma} \right)^{\frac{1}{1-\sigma}}$$

Firm Revenue

- Aggregate intermediate goods sales can be expressed as

$$R_i(\omega) = Z_i(\omega)^{\sigma-1} w_i^{\beta_L(1-\sigma)} \mathcal{A}_i^S(\omega) \mathcal{A}_i^B(\omega),$$

with supplier and buyer access (cf. Redding-Venables '04, Donaldson-Hornbeck '16):

$$\mathcal{A}_i^S(\omega) \equiv \left(\sum_{u \in \mathcal{L}} \sum_{\upsilon \in \Omega_u} M_{ui}(\upsilon, \omega) \tau_{ui}(\upsilon, \omega)^{1-\sigma} C_u(\upsilon)^{1-\sigma} \right)^{\beta},$$

$$\mathcal{A}_i^B(\omega) \equiv \sum_{d \in \mathcal{L}} \sum_{\psi \in \Omega_d} M_{id}(\omega, \psi) \tau_{id}(\omega, \psi)^{1-\sigma} D_d^*(\psi).$$

- Summarize the effect of supply chain disruption and reorganization under GE

Multi-Sector Model

- Firms belong to a sector $k \in K$
- Cobb-Douglas production with input share β_{km} with sector-specific elasticity of substitution σ_k

$$Y_{i,m}(\omega) = Z_{i,m}(\omega) \left(\frac{L_{i,m}(\omega)}{\beta_{m,L}} \right)^{\beta_{m,L}} \prod_{k \in K} \left(\frac{Q_{i,km}(\omega)}{\beta_{km}} \right)^{\beta_{km}}$$

$$Q_{i,km}(\omega) = \left(\sum_{u \in \mathcal{L}} \sum_{v \in \Omega_{u,k}} M_{ui,km}(v,\omega) q_{ui,km}(v,\omega)^{\frac{\sigma_k - 1}{\sigma_k}} \right)^{\frac{\sigma_k}{\sigma_k - 1}}$$

- Final consumption share α_k
- Measure of linkages: $M_{ui,km}(v,\omega)$

Quantitative Analysis

Calibration

- 25 regions (oblasts) + "conflict area"
- Three sectors: mining, manufacturing, other
- 4 firm types within region-sector based on high/low supplier and buyer exposures (85th percentiles) prior to the conflict
- Trade flows and production linkages: impute from railway shipment data

Calibrate Structural Parameters from Ukraine's Pre-War IO Table

- $\{\beta_{L,m}, \beta_{km}, \alpha_k\}$: Input and final expenditure shares
- $\{\sigma_k\}$: (Pre-tax) profit to revenue ratio

	Sectors (m)		
	Mining	Manufacturing	Other
(a) β_{km}			
k =Mining	0.11	0.12	0.06
k =Manufacturing	0.18	0.33	0.18
k =Other	0.36	0.45	0.40
(b) $\beta_{m,L}$	0.35	0.10	0.36
(c) α_m	0.01	0.6	0.39
(d) σ_m	4.8	8.1	5.0

Model Validation: Can the Model Explain Observed Changes in Firm Output?

- Model-predicted intermediate goods sales in year t by firm type ω in region i and sector k

$$\log\left[w_{i,t}^{\beta_{m,L}(1-\sigma_m)}\mathcal{A}_{i,m,t}^{S}(\omega)\mathcal{A}_{i,m,t}^{B}(\omega)\right] = \log R_{i,m,t}(\omega) - \log Z_{i,m,t}(\omega)^{\sigma_m-1}$$

- We validate our model by estimating:

$$\log\left[w_{i,t}^{\beta_{m,L}(1-\sigma_m)}\tilde{\mathcal{A}}_{i,m,t}^{S}(\omega)\tilde{\mathcal{A}}_{i,m,t}^{B}(\omega)\right] = \gamma \log R_{i,m,t}(\omega) + \eta_{i,m}(\omega) + \nu_{i,t} + \delta_{m,t} + \epsilon_{i,m,t}(\omega)$$

  - $\tilde{\mathcal{A}}_{i,m,t}^{S}(\omega), \tilde{\mathcal{A}}_{i,m,t}^{B}(\omega)$: estimate from panel gravity equations using railway data (next slide)

- IV: high supplier and buyer exposures $\times$ post
  - If TFP changes are uncorrelated with IVs, $\gamma = 1$ (cf. Adao, Costinot, Donaldson '23)

Estimating Supplier and Buyer Accesses

- Model-predicted trade flows (with time subscript t):

$$\frac{X_{ui,km,t}(\upsilon,\omega)}{M_{ui,km,t}(\upsilon,\omega)} = C_{u,k,t}(\upsilon)^{1-\sigma_k} D_{i,km,t}(\omega)\tau_{ui,km,t}(\upsilon,\omega)^{1-\sigma_k}$$

- We estimate a three-way fixed-effect model by PPML:

$$\frac{X_{ui,km,t}(\upsilon,\omega)}{M_{ui,km,t}(\upsilon,\omega)} = \xi_{u,km,t}(\upsilon)\zeta_{i,km,t}(\omega)\eta_{ui,km}(\upsilon,\omega)\epsilon_{ui,km,t}(\upsilon,\omega)$$

- Using these estimates,

$$\tilde{\mathcal{A}}^{S}_{i,m,t}(\omega) = \sum_{k\in K}\left(\sum_{u\in\mathcal{L}}\sum_{\upsilon\in\Omega_{u,k}} M_{ui,km,t}(\upsilon,\omega)\tilde{\eta}_{ui,km}(\upsilon,\omega)\tilde{\xi}_{u,km,t}(\upsilon)\right)^{\beta_{km}}$$

$$\tilde{\mathcal{A}}^{B}_{i,m,t}(\omega) = \sum_{l\in K}\sum_{d\in\mathcal{L}}\sum_{\psi\in\Omega_{d,l}} M_{id,ml,t}(\omega,\psi)\tilde{\eta}_{ui,km}(\omega,\psi)\tilde{\zeta}_{i,km,t}(\psi)$$

- Two scenarios: Use observed $M_{ui,km,t}(\upsilon,\omega)$ for each year ("with link adjustment") and $M_{ui,km,2013}(\upsilon,\omega)$ ("without link adjustment")

	$\log w_{i,t}^{\beta_{m,L}(1-\sigma_m)} \tilde{A}^S_{i,m,t}(\omega) \tilde{A}^B_{i,m,t}(\omega)$				
	(1)	(2)	(3)	(4)	(5)
Panel A: With Link Adjustment					
$\log R_{i,m,t}(\omega)$	1.12	1.13	1.16	0.97	1.44
	(0.17)	(0.19)	(0.19)	(0.25)	(0.51)
p-value (coefficient = 1)	0.50	0.50	0.41	0.92	0.39
Panel B: Without Link Adjustment					
$\log R_{i,m,t}(\omega)$	0.42	0.45	0.47	0.25	0.97
	(0.13)	(0.14)	(0.12)	(0.14)	(0.47)
p-value (coefficient = 1)	0.00	0.00	0.00	0.00	0.96
IV	High Buyer and Supplier Exposure			High Buyer Exposure	High Supplier Exposure
Cluster-Robust First-Stage F-Statistics	26.4	27.6	27.3	11.5	4.2
Observations	427	427	427	427	427
Firm-Type-Region-Sector Fixed Effects	✓	✓	✓	✓	✓
Year Fixed Effects	✓	✓	✓	✓	✓
Sector × Year Fixed Effects		✓	✓	✓	✓
Region × Year Fixed Effects			✓	✓	✓

- Cannot reject $\gamma = 1$ with link changes; reject $\gamma = 1$ without link changes

shut down only buyer & supplier links | use all years | reestimate gravity with aggregate flows

Quantify Welfare Loss Outside Conflict Areas

- Calibrate model with 2013 trade and production linkage patterns
- Simulate $\tau_{ui,km}(\upsilon,\omega) \to \infty$ if u or i is in conflict areas
- Reorganization of supplier linkages $\{M_{ui,km}(\upsilon,\omega)\}$ based on diff-in-diff estimates
  - $+10.3$ log pts if firm type ω is high supplier exposure (uniform across suppliers)
  - -6.0 log pts if firm type ω is high buyer exposure
  - 0 if low supplier & buyer exposures
- Robustness: change probability depending on whether *suppliers* are hit by a shock to simultaneously rationalize diff-in-diff estimates on buyer linkages

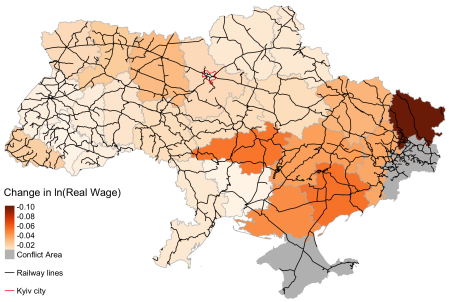
Large Welfare Loss, Large But Offsetting Effects from Reorganization

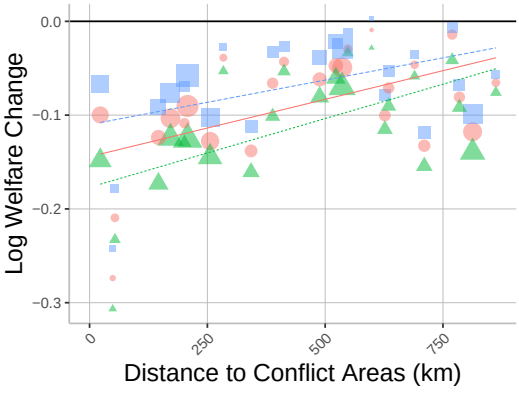
Percentage Point Reduction in Welfare	Mean	25%-ile	50%-ile	75%-ile
(1) Baseline (With Supplier Link Adjustment)	-9.1	-11.8	-9.0	-4.9
(2) Shut Down Supplier Link Adjustment by High Supplier Exposure Firms	-11.4	-14.5	-12.4	-7.0
(3) Shut Down Supplier Link Adjustment by High Buyer Exposure Firms	-6.8	-9.1	-6.6	-3.2
(4) No Link Adjustment	-9.1	-11.9	-9.3	-5.1

- Row (2): Abstracting from $\uparrow$ supplier linkages by high supplier exposure increases aggregate welfare loss (mitigation)
- Row (3): Abstracting from $\downarrow$ supplier linkages by high buyer exposure decreases aggregate welfare loss (amplification)
- Row (4): The two effects roughly offset

robustness

Negative Effects Even for Distant Region from Conflict Areas





Conclusion

Conclusion

- Provide reduced-form evidence of significant supply chain disruption and reorganization during 2014 Ukraine War, beyond Donbas and Crimea
- Large welfare loss even outside and far from conflict areas
- Highlights a key mechanism in which localized conflict often have far-reaching detrimental consequences for the broader economy (Rohner & Thoenig '21)

Appendix

THE WALL STREET JOURNAL.

BUSINESS

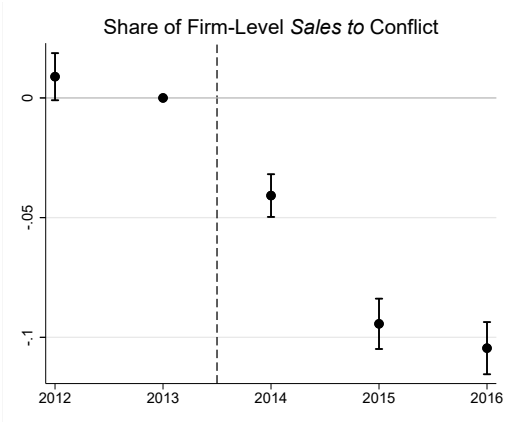
Tesla to Halt Production in Germany as Red Sea Conflict Hits Supply Chains

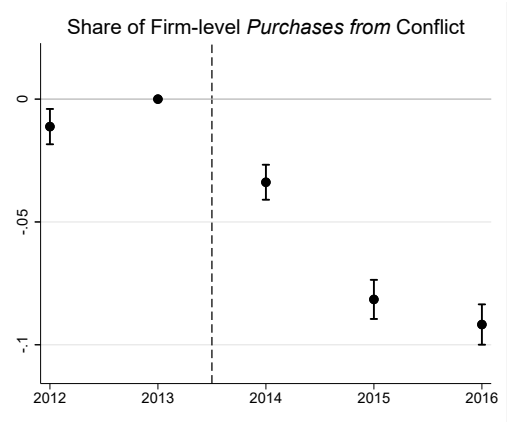
Disruption related to attacks on ships by Houthi rebels raise risk of supply-chain crisis in Europe

By *William Boston* Follow, *Costas Paris* Follow and *Benoit Faucon* Follow

Updated Jan. 12, 2024 at 1:45 pm ET

Sudden and Large Drop of Trade from & to Conflict Areas

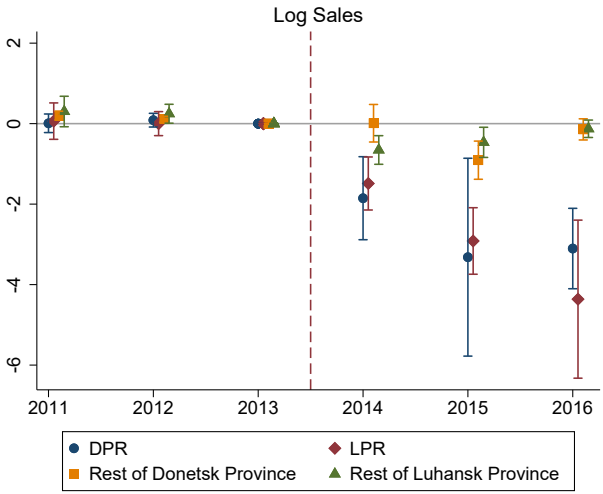




Sudden and Large Drop of Aggregate Firm Sales in Conflict Areas

$$
\begin{aligned}
Y_{rt} = & \beta_t^{LPR} \times \text{LPR}_r \times \text{Post}_t \\
& + \beta_t^{DPR} \times \text{DPR}_r \times \text{Post}_t \\
& + \beta_t^{DON} \times \text{Donetsk}_r \times \text{Post}_t \\
& + \beta_t^{LUH} \times \text{Luhansk}_r \times \text{Post}_t \\
& + \alpha_r + \kappa_t + \varepsilon_{rt}
\end{aligned}
$$

- r: rayon (district)
- Exclude Crimea due to data quality after the annexation
- Consistent with decline in nighttime light (Kochnev '19)



Impacts of Supplier and Buyer Conflict Exposures on Sales

	(1) Log Sales	(2) No Sales Reported	(3) Log Sales	(4) No Sales Reported	(5) Log Sales	(6) No Sales Reported
Post-2014 × 𝟙[Firm traded with conflict areas, 2012–13]	-0.183***	0.088***				
	(0.046)	(0.010)				
Post-2014 × Firm's buyer conflict exposure, 2012–13			-0.265**	0.074***		
			(0.109)	(0.025)		
Post-2014 × Firm's supplier conflict exposure, 2012–13			-0.316***	0.106***		
			(0.103)	(0.022)		
Post-2014 × 𝟙[High firm's buyer conflict exposure, 2012–13]					-0.197***	0.051***
					(0.069)	(0.014)
Post-2014 × 𝟙[High firm's supplier conflict exposure, 2012–13]					-0.167**	0.069***
					(0.066)	(0.014)
Firm FE	✓	✓	✓	✓	✓	✓
Year FE	✓	✓	✓	✓	✓	✓
Mean	16.890	0.327	16.890	0.327	16.890	0.327
SD	2.484	0.469	2.484	0.469	2.484	0.469
Observations	35,029	52,272	35,029	52,272	35,029	52,272
Number of Firms	4,802	6,071	4,802	6,071	4,802	6,071

Summary Statistics of Exposures with Conflict Areas and with Russia

	Observations	Mean	SD	Min	Max
$\mathbb{1}$[Firm traded with conflict areas, 2012–13]	52,294	0.55	0.50	0	1
Firm's buyer conflict exposure, 2012–2013	52,294	0.09	0.21	0	1
Firm's supplier conflict exposure, 2012–2013	52,294	0.10	0.23	0	1
$\mathbb{1}$[High firm's buyer conflict exposure, 2012–13]	52,294	0.14	0.35	0	1
$\mathbb{1}$[High firm's supplier conflict exposure, 2012–13]	52,294	0.14	0.35	0	1
$\mathbb{1}$[Firm traded with Russia in 2012–2013]	52,294	0.23	0.42	0	1

Impacts of Supplier and Buyer Conflict Exposures on Sales: Robustness

	(1) Baseline	(2) Strictly balanced panel	(3) Latitude & longitude	(4) Latitude & longitude	(5) Distance to conflict areas	(6) Distance to conflict areas	(7) 2-digit industry × post	(8) Region FE × post	(9) Pre-conflict trade with Russia	(10) Pre-conflict trade partners	(11) Omitting Donetsk oblast	(12) Omitting Luhansk oblast	(13) Omitting Kyiv
Post-2014 × $\mathbb{1}$[Firm traded with conflict areas, 2012–13]	-0.183*** (0.046)	-0.116** (0.046)	-0.152*** (0.046)	-0.138*** (0.046)	-0.155*** (0.046)	-0.161*** (0.046)	-0.134*** (0.048)	-0.116** (0.046)	-0.146*** (0.046)	-0.167*** (0.047)	-0.147*** (0.047)	-0.176*** (0.047)	-0.151*** (0.048)
Post-2014 × Latitude			0.073*** (0.016)	-1.380 (0.946)									
Post-2014 × Longitude			-0.024*** (0.006)	-1.057*** (0.293)									
Post-2014 × Latitude^2				0.007 (0.010)									
Post-2014 × Longitude^2				-0.003** (0.001)									
Post-2014 × Latitude × longitude				0.024*** (0.006)									
Post-2014 × Distance to conflict area					0.614*** (0.101)								
Post-2014 × Distance to LPR or DPR						0.464*** (0.082)							
Post-2014 × $\mathbb{1}$[Firm imported from Russia, 2012–13]									-0.221*** (0.062)				
Post-2014 × $\mathbb{1}$[Firm exported to Russia, 2012–13]									-0.224*** (0.064)				
Post-2014 × # of pre-conflict trade partners										-0.000** (0.000)			
Firm FE	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Year FE	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Mean	16.890	17.232	16.890	16.890	16.890	16.890	16.920	16.890	16.890	16.890	16.854	16.893	16.837
SD	2.484	2.289	2.483	2.483	2.483	2.483	2.475	2.484	2.484	2.484	2.458	2.478	2.439
Observations	35,029	23,616	34,922	34,922	34,922	34,922	33,520	35,029	35,029	35,029	32,920	34,316	30,176
Number of Firms	4,802	2,624	4,779	4,779	4,779	4,779	4,599	4,802	4,802	4,802	4,486	4,683	4,065

Market clearing (multiple sector)

- Final goods sales

$$R_{i,m}^{F}(\omega) = \frac{\varsigma_m N_{i,m}(\omega)\, C_{i,m}(\omega)^{1-\sigma_k}}{\left(P_{i,m}^{F}\right)^{1-\sigma_m}} \alpha_m E_i L_i$$

- Intermediate goods sales

$$R_{i,m}(\omega) = \tilde{\varsigma}_m Z_{i,m}(\omega)^{\sigma_m - 1} w_i^{\beta_{m,L}(1-\sigma_m)} \mathcal{A}_{i,m}^{S}(\omega) \mathcal{A}_{i,m}^{B}(\omega),$$

- Labor market clearing

$$w_i L_i = \sum_{m \in K} \beta_{L,m} \frac{\sigma_m - 1}{\sigma_m} \left(R_{i,m}(\omega) + R_{i,m}^{F}(\omega) \right),$$

- Firm profit

$$\pi_{i,m}(\omega) = \sum_{m \in K} \frac{1}{\sigma_m} \left(R_{i,m}(\omega) + R_{i,m}^{F}(\omega) \right).$$

Model Validation: Shut Down Only Buyer Linkage Changes

	$\log w_{i,t}^{\beta_{m,L}(1-\sigma_m)} \tilde{A}^S_{i,m,t}(\omega).\tilde{A}^B_{i,m,t}(\omega)$				
	(1)	(2)	(3)	(4)	(5)
$\log R_{i,m,t}(\omega)$	0.42	0.40	0.44	0.25	0.70
	(0.13)	(0.14)	(0.13)	(0.17)	(0.41)
p-value (coefficient = 1)	0.00	0.00	0.00	0.00	0.46
Cluster-Robust First-Stage F-Statistics	26.4	27.6	27.3	11.5	4.2
IV	High Buyer and Supplier Exposures	High Buyer and Supplier Exposures	High Buyer and Supplier Exposures	High Buyer Exposure	High Supplier Exposure
Firm-Type-Region-Sector Fixed Effects	X	X	X	X	X
Year Fixed Effects	X	X	X	X	X
Sector × Year Fixed Effects		X	X	X	X
Region × Year Fixed Effects			X	X	X
Observations	426	426	426	426	426
Adjusted R^2	1.00	1.00	1.00	1.00	0.99

Model Validation: Shut Down Only Supplier Linkage Changes

	$\log w_{i,t}^{\beta_{m,L}(1-\sigma_m)} \tilde{A}^S_{i,m,t}(\omega).\tilde{A}^B_{i,m,t}(\omega)$				
	(1)	(2)	(3)	(4)	(5)
$\log R_{i,m,t}(\omega)$	1.11	1.17	1.18	0.98	1.69
	(0.16)	(0.17)	(0.16)	(0.18)	(0.50)
p-value (coefficient = 1)	0.48	0.32	0.27	0.90	0.17
Cluster-Robust First-Stage F-Statistics	31.4	33.7	36.8	15.1	6.1
IV	High Buyer and Supplier Exposures	High Buyer and Supplier Exposures	High Buyer and Supplier Exposures	High Buyer Exposure	High Supplier Exposure
Firm-Type-Region-Sector Fixed Effects	X	X	X	X	X
Year Fixed Effects	X	X	X	X	X
Sector × Year Fixed Effects		X	X	X	X
Region × Year Fixed Effects			X	X	X
Observations	427	427	427	427	427
Adjusted R^2	1.00	0.99	0.99	1.00	0.99

Model Validation: Use All Years

	$\log w_{i,t}^{\beta_{m,L}(1-\sigma_m)} \tilde{A}^S_{i,m,t}(\omega) \tilde{A}^B_{i,m,t}(\omega)$				
	(1)	(2)	(3)	(4)	(5)
$\log R_{i,m,t}(\omega)$	1.24	1.27	1.33	1.06	1.67
	(0.21)	(0.22)	(0.23)	(0.35)	(0.51)
p-value (coefficient = 1)	0.25	0.23	0.15	0.86	0.19
Cluster-Robust First-Stage F-Statistics	22	23.5	22.5	6.1	5.3
IV	High Buyer and Supplier Exposures	High Buyer and Supplier Exposures	High Buyer and Supplier Exposures	High Buyer Exposure	High Supplier Exposure
Firm-Type-Region-Sector Fixed Effects	X	X	X	X	X
Year Fixed Effects	X	X	X	X	X
Sector × Year Fixed Effects		X	X	X	X
Region × Year Fixed Effects			X	X	X
Observations	1,057	1,057	1,057	1,057	1,057
Adjusted R^2	0.99	0.99	0.99	1.00	0.99

Model Validation: Estimate Gravity using Aggregate Flows

	$\log w_{i,t}^{\beta_{m,L}(1-\sigma_m)} \tilde{A}^S_{i,m,t}(\omega) \tilde{A}^B_{i,m,t}(\omega)$				
	(1)	(2)	(3)	(4)	(5)
$\log R_{i,m,t}(\omega)$	1.65	1.67	1.66	1.23	2.51
	(0.25)	(0.27)	(0.27)	(0.31)	(0.98)
p-value (coefficient = 1)	0.01	0.01	0.02	0.45	0.12
Cluster-Robust First-Stage F-Statistics	26.4	27.6	27.3	11.5	4.2
IV	High Buyer and Supplier Exposures	High Buyer and Supplier Exposures	High Buyer and Supplier Exposures	High Buyer Exposure	High Supplier Exposure
Firm-Type-Region-Sector Fixed Effects	X	X	X	X	X
Year Fixed Effects	X	X	X	X	X
Sector × Year Fixed Effects		X	X	X	X
Region × Year Fixed Effects			X	X	X
Observations	427	427	427	427	427
Adjusted R^2	0.99	0.99	0.99	0.99	0.97

Counterfactual Simulation: Robustness

	Welfare Change (Percent)			
Alternative Specifications	(1) Baseline (With Supplier Link Adjustment)	(2) Shut Down Supplier Link Adjustment by Supplier Exposure	(3) Shut Down Supplier Link Adjustment by Buyer Exposure	(4) No Supplier Link Adjustment)
(a) Baseline	-9.1	-11.4	-6.8	-9.1
(b) Match Impacts on Both Supplier and Buyer Linkages	-8.8			
(c) Add Entry/Exit Effects	-10.0	-12.4	-7.7	-10.0
(d) Alternate Value Imputation (log(average Value/Weight))	-9.5	-11.9	-7.2	-9.5
(e) Alternate Value Imputation (average log(Value/Weight), Export)	-11.8	-13.9	-9.4	-11.6
(f) Alternate Value Imputation (log(average Value/Weight), Export)	-12.2	-14.3	-9.8	-12.0
(g) Define Types by Link Exposures	-9.0	-10.2	-7.0	-8.2
(h) Define Types by Weight Exposures	-7.8	-9.7	-5.8	-7.7