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Regional Integration and Economic Resilience

Propagation of Disaster Shocks through Global Supply Chains

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Motivation

Input-output linkages
across **sectors**

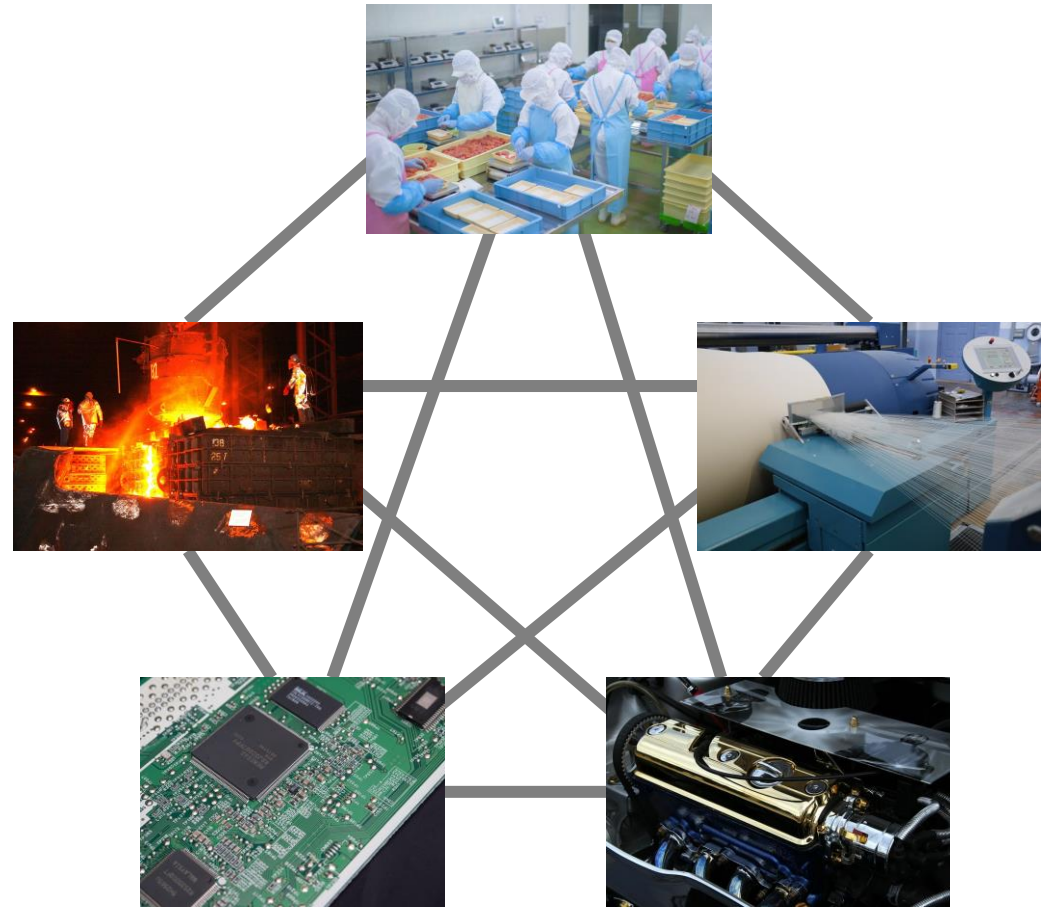


Propagation of
shocks



Aggregate
fluctuations

(Acemoglu et al. 2012;
Caliendo et al. 2014;
Di Giovanni et al. 2010)



Empirical analysis
at the industry level

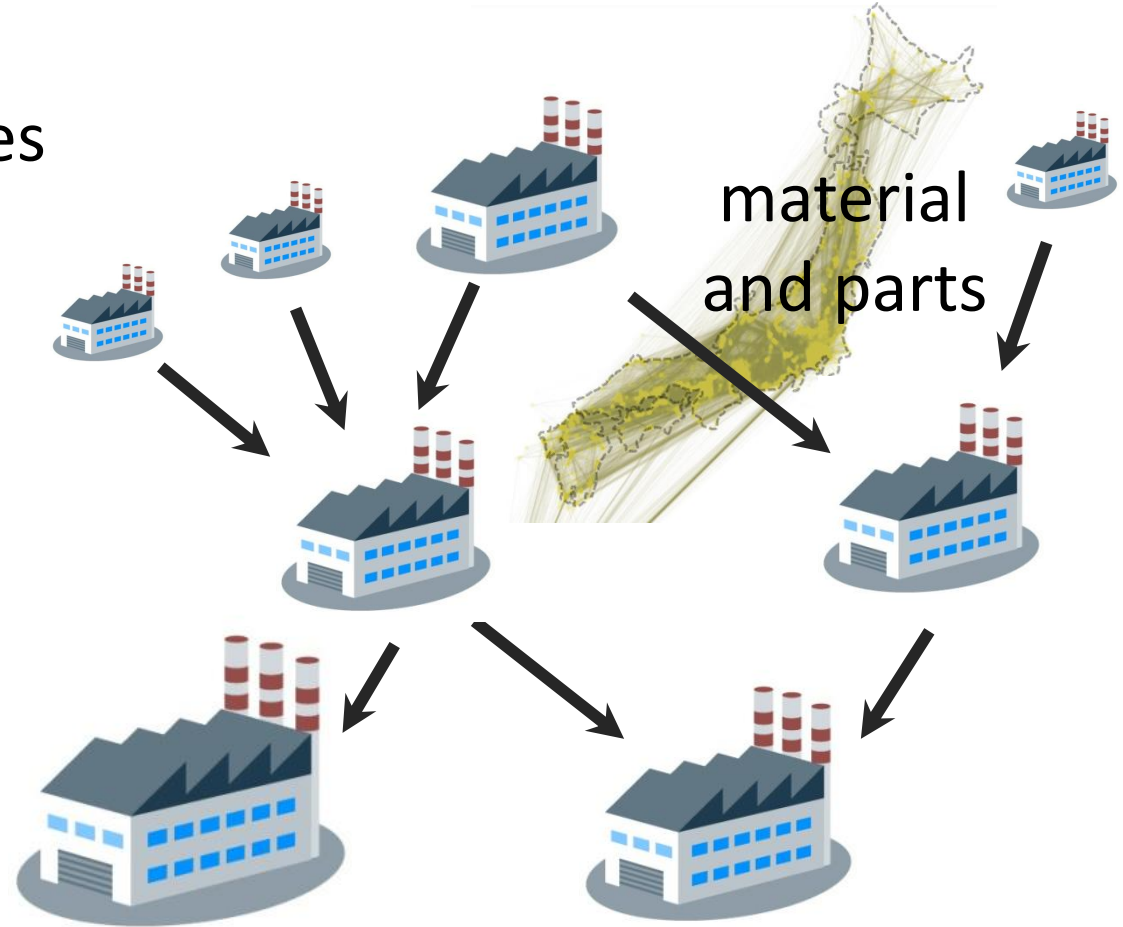
Motivation

Input-output linkages
across **firms**



Propagation of
shocks due to
natural disasters

(Barrot et al. 2016;
Carvalho et al. 2014;
Lu et al. 2017)



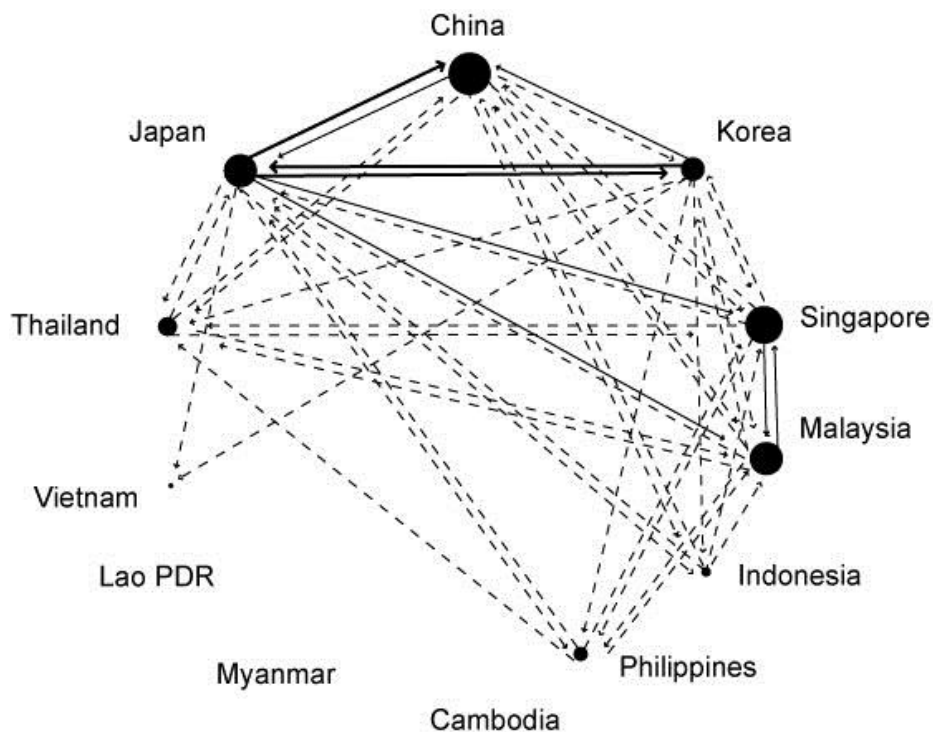
Empirical analysis
restricted to supply chains
within a country

But global supply chains
have expanded recently

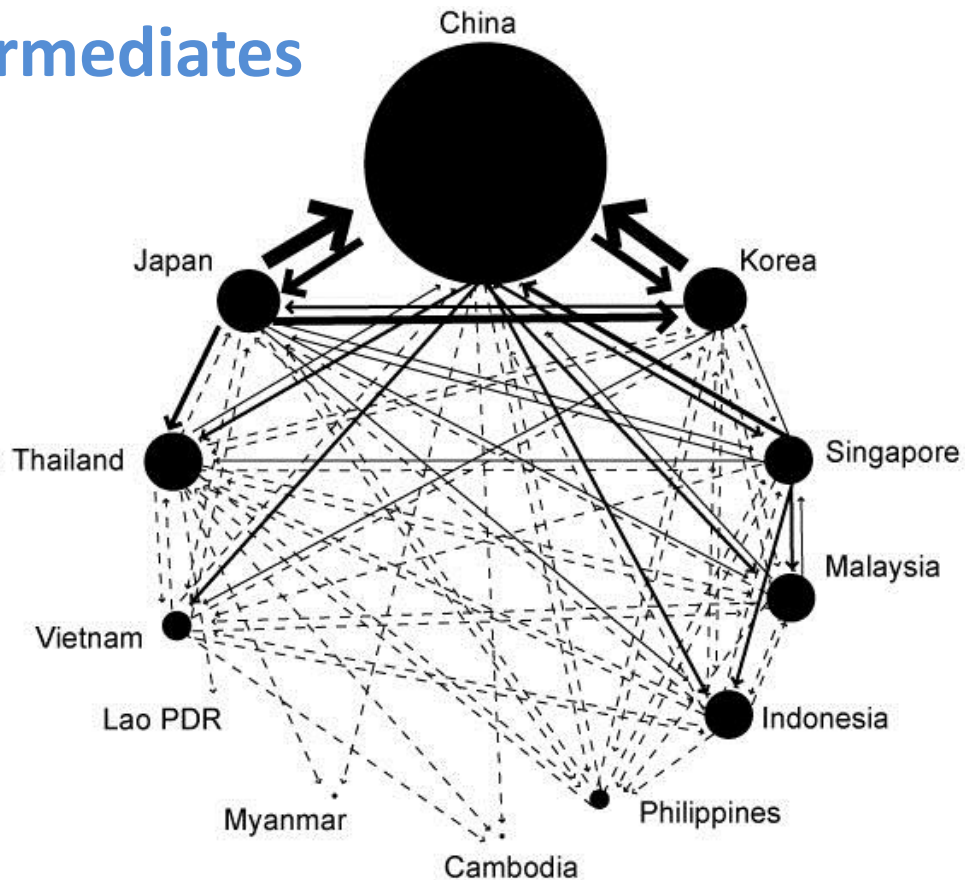
Motivation

2000

Trade in intermediates



2012



This Paper

Research question

- How do negative shocks due to Hurricane Sandy in US propagate through global supply chains?

Contributions

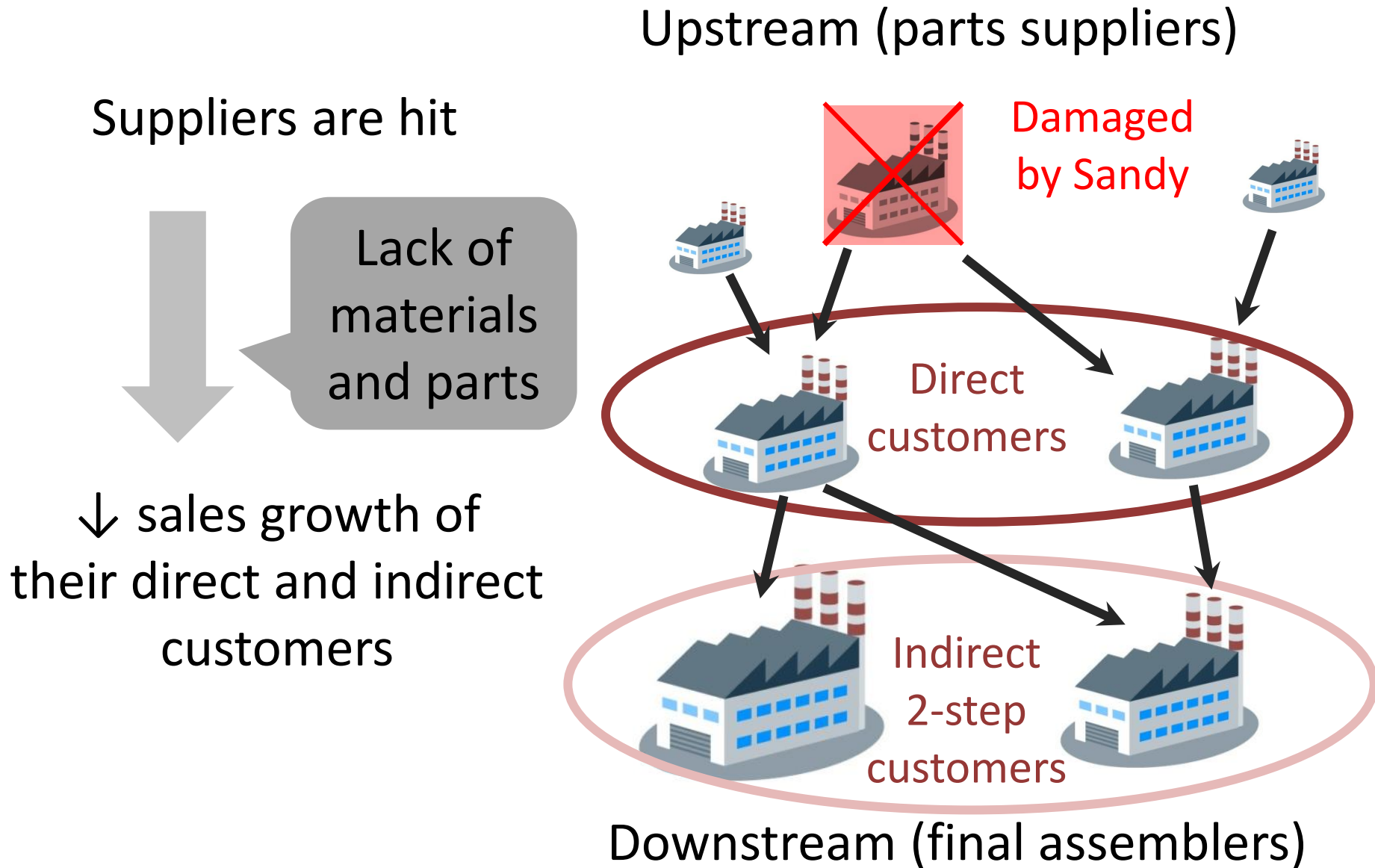
- Large firm-level data for global supply chains
- Effects of measures of networks (e.g., diversity)
- Effects of supply chains + shareholding and R&D networks

US Hurricane Sandy

- Hit the east coast of the US in October 2012
- 2nd largest disaster in the world since 2010 (in terms of economic damages)
 - Estimated 10,000 manufacturing facilities were directly affected
 - \$20 billion in total infrastructure damage

Source:
Daily News, Nov. 1, 2012

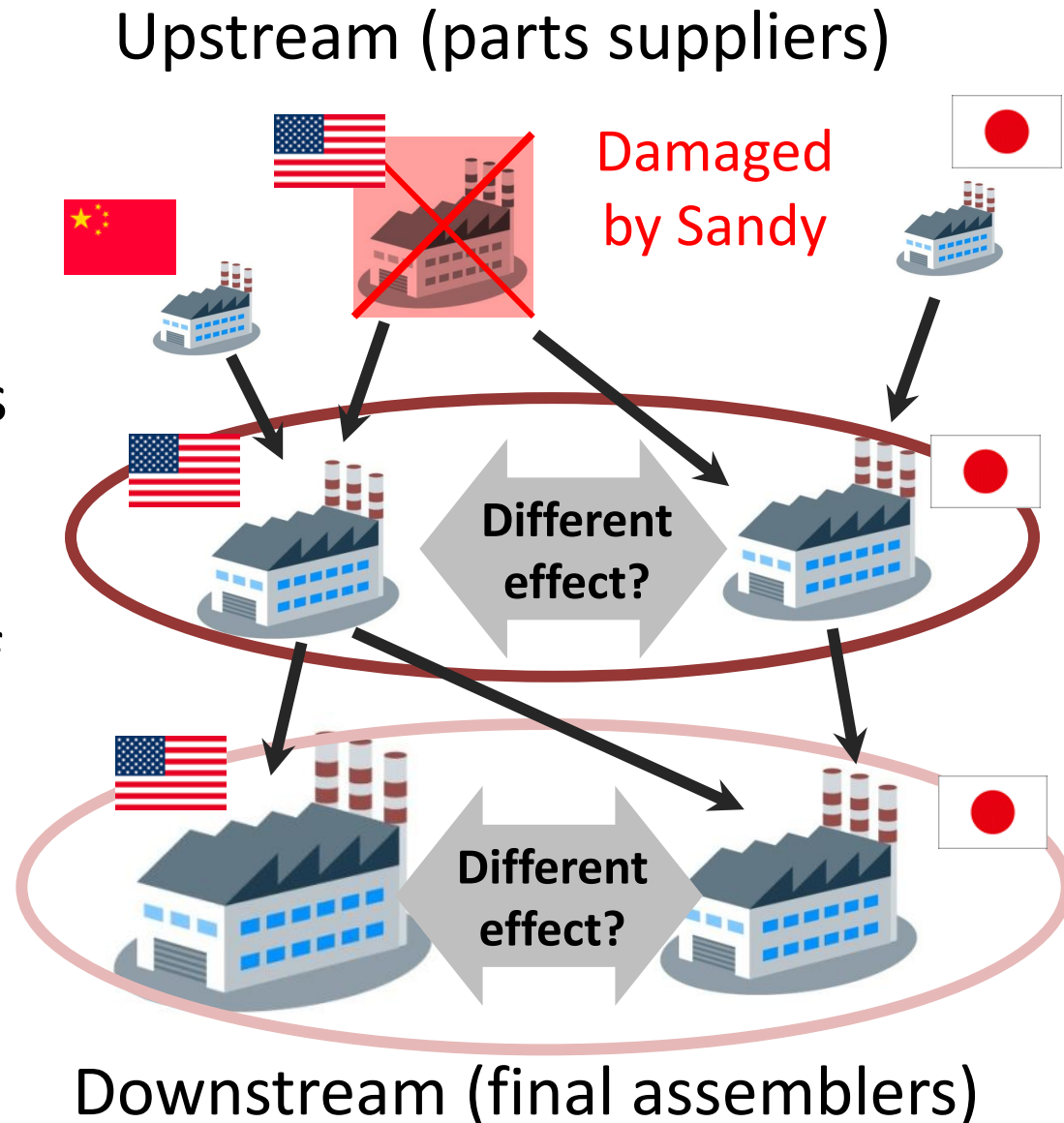
Hypothesis: Propagation of shocks



Hypothesis: Intra- and inter-national effect

Propagation effect on US customers

- > on non-US if non-US customers are well diversified
- < on non-US if large specificity of US inputs

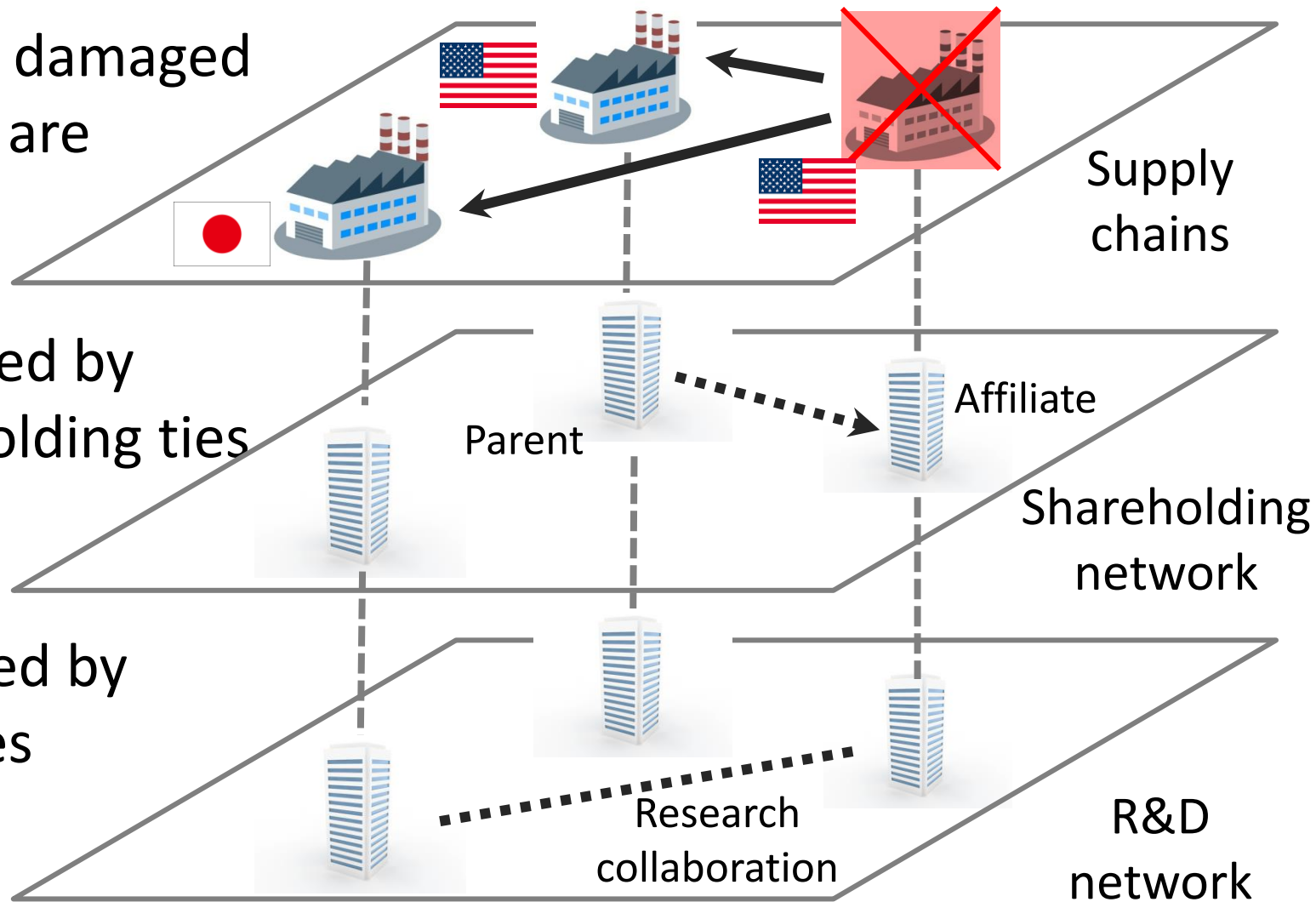


Hypothesis: Multi-layered networks

Effects of damaged suppliers are

- alleviated by shareholding ties

- amplified by R&D ties



Estimation Equation

$$\begin{aligned} \text{Sales growth}_{i,2011-12/13} \\ = \beta_0 + \beta_1 \text{Supplier}_{i,2011} + \beta_2 X_{i,2011} + \varepsilon_i \end{aligned}$$

- *Supplier*: vector of measures of supply chain ties
 - #/dummy of **direct ties** with damaged suppliers
 - #/dummy of **indirect ties** with damaged suppliers in 2 steps
 - #/dummy above * non-US dummy
 - ➔ difference b/w **intra- and inter-national** propagation

Estimation Equation

$$\begin{aligned} \text{Sales growth}_{i,2011-12/13} \\ = \beta_0 + \beta_1 \text{Supplier}_{i,2011} + \beta_2 X_{i,2011} + \varepsilon_i \end{aligned}$$

- X : vector of controls
 - **Burt's constraint**: an inverse measure of diversity of supply chain partners
 - **Local clustering coefficient**: a measure of density of supply chain partners
 - Other standard firm attributes
 - Industry and country dummies

Estimation Strategy

- OLS with clustered robust standard errors
- Identified because whether each firm is linked with damaged firms is exogenously determined.
 - Pre-disaster sales growth was not systematically different b/w firms linked with damaged suppliers and others.

	(1)	(2)	(3)	(4)
	Dependent variable:			
	Sales growth from 2009 to 2011		Sales growth from 2006 to 2011	
Dummy for link with damaged suppliers	0.0188 (0.0474)		-0.00712 (0.0157)	
Dummy for 2-step link with damaged suppliers		0.00621 (0.0371)		0.00535 (0.0123)
Observations	2,739	2,739	2,748	2,748
R-squared	0.013	0.013	0.063	0.063

Data

LiveData (FactSet Revere)

- Supply chain information for mostly public firms from open sources, e.g., financial reports and web sites

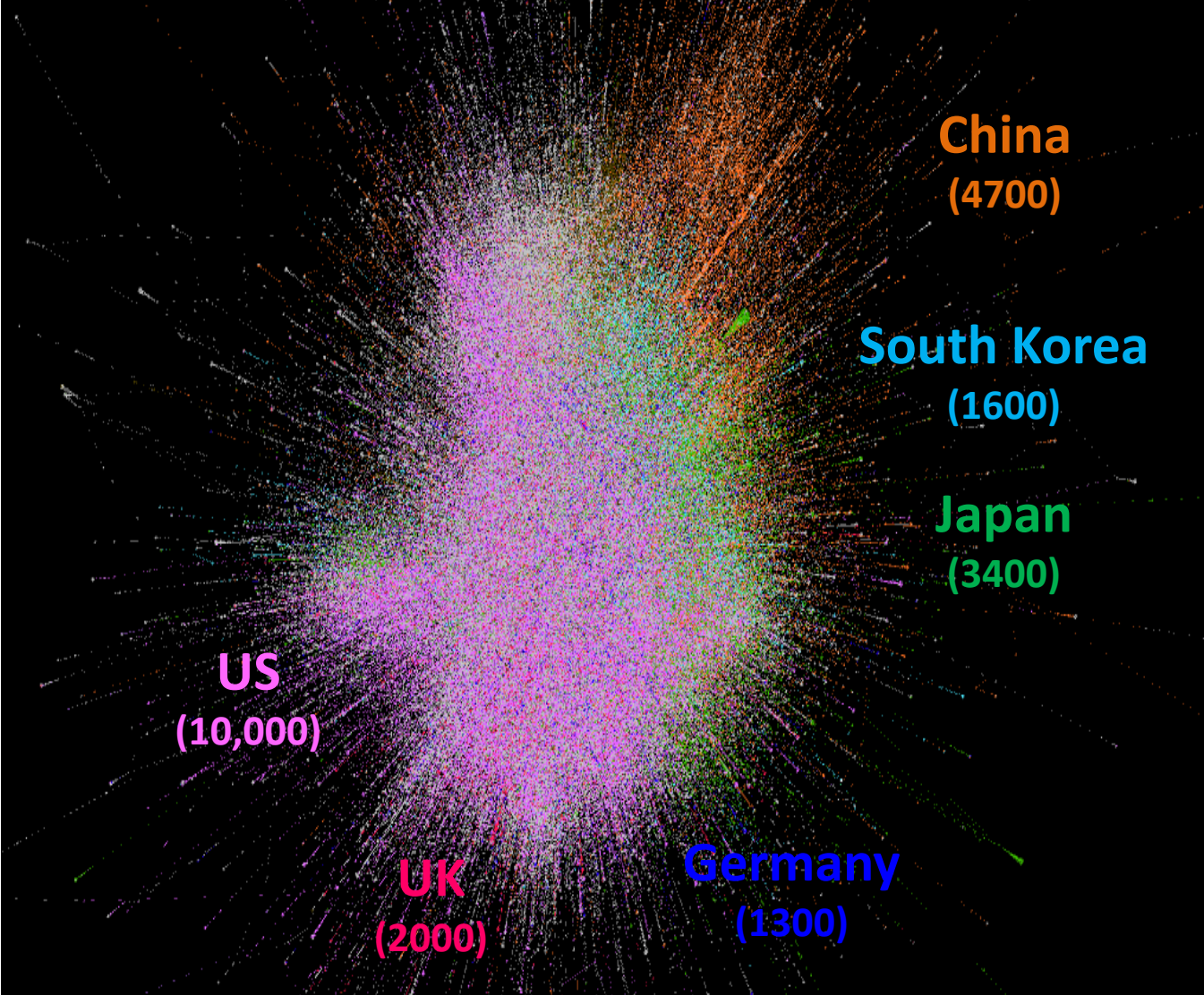
Orbis (Bureau van Dijk)

- Large firms level data (200 million firms)
- Shareholding and patent co-application relations

Osiris (Bureau van Dijk)

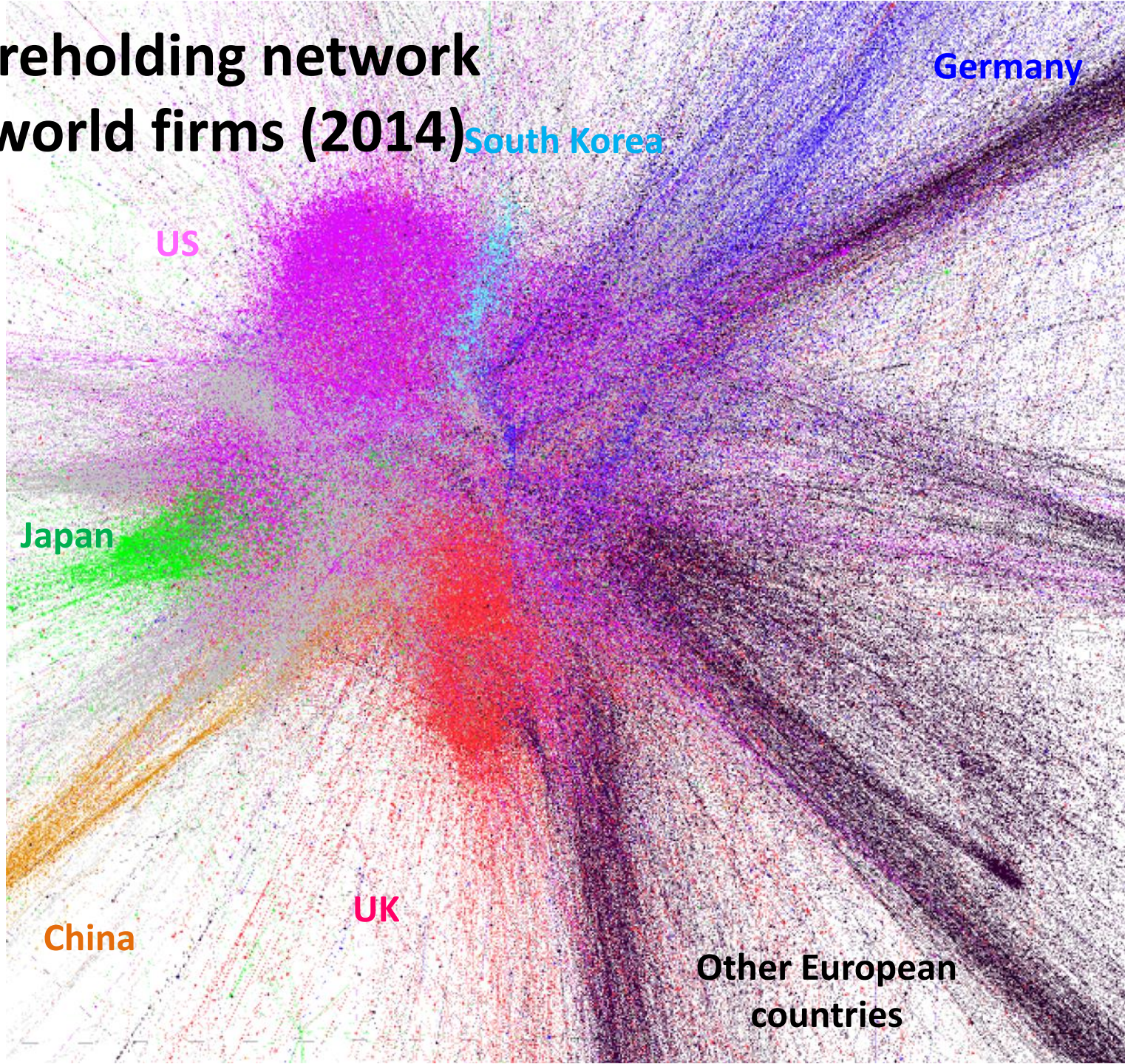
- Public-firm version of Orbis
- Detailed financial information

Supply chains of major firms around the world (2015)

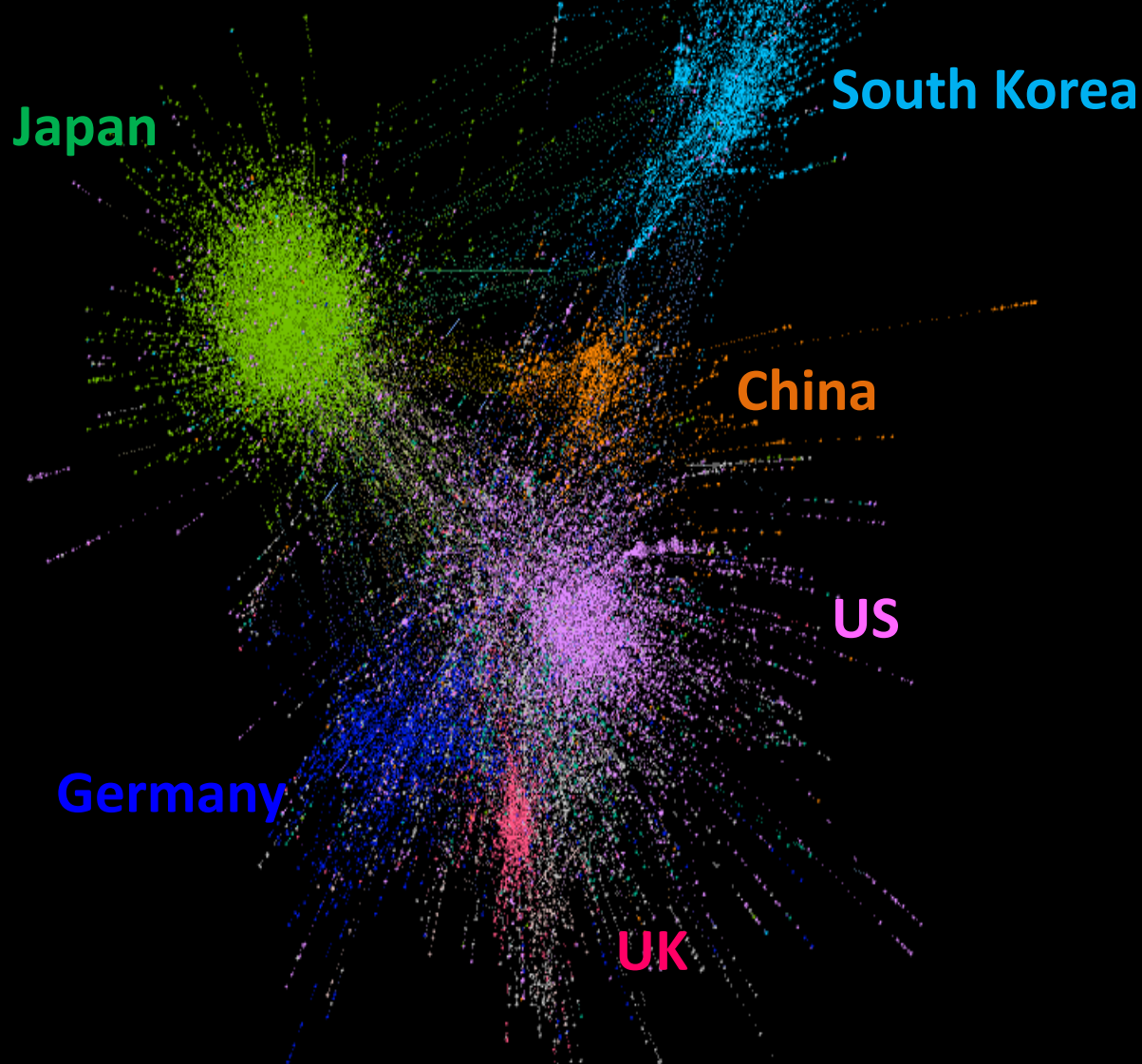


Source:
FactSet
Revere
Visualized
by Gephi
using
ForceAtlas2

Shareholding network of world firms (2014)



Patent co-ownership networks of firms around the world in 2011-13



Data

Combine LiveData, Osiris, and Orbis using ISIN

➔ Focus on large/publicly listed firms

➔ $N = 2,748$

Country	<i>N</i>	%
Bermuda	14	0.51
Brazil	20	0.73
Canada	11	0.40
Switzerland	46	1.67
Chile	20	0.73
China	284	10.33
Germany	81	2.95
Spain	10	0.36
France	96	3.49
United Kingdom	147	5.35
Indonesia	98	3.57
Ireland	10	0.36
Israel	43	1.56
Italy	30	1.09
Japan	111	4.04

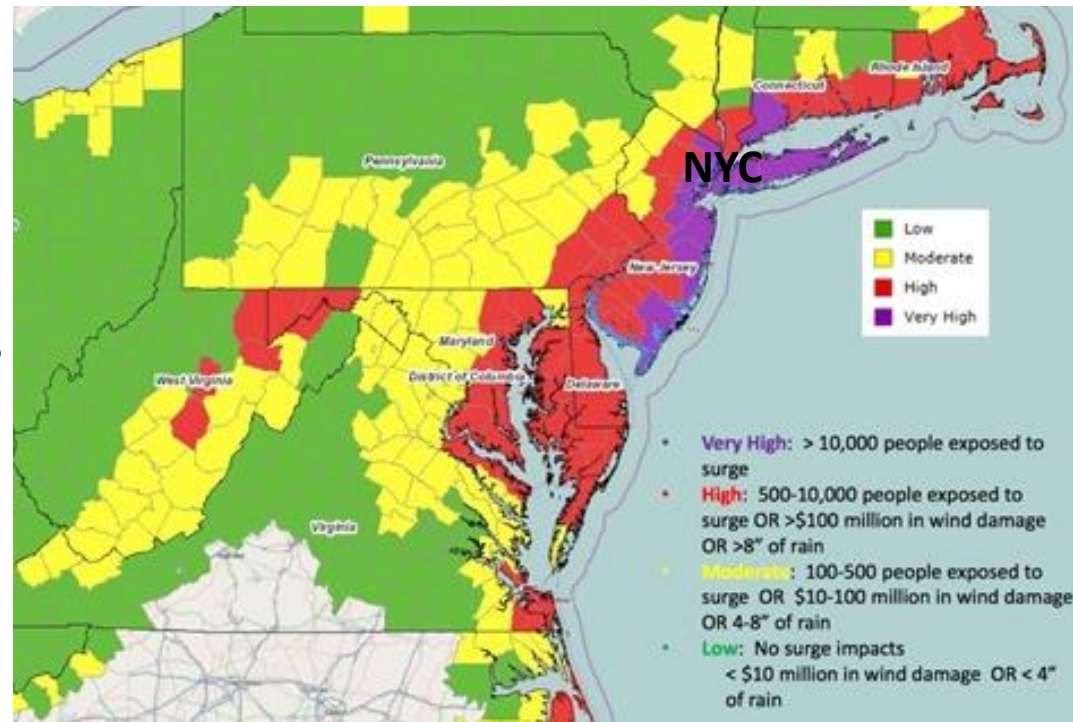
Country	<i>N</i>	%
Japan	111	4.04
Cayman Islands	13	0.47
Oman	13	0.47
Russia	13	0.47
Saudi Arabia	20	0.73
Sweden	29	1.06
Turkey	62	2.26
Taiwan	29	1.06
United States	1,450	52.77
Total	2,748	100

Data

FEMA Disaster Declaration Data

- Damaged areas by Hurricane Sandy

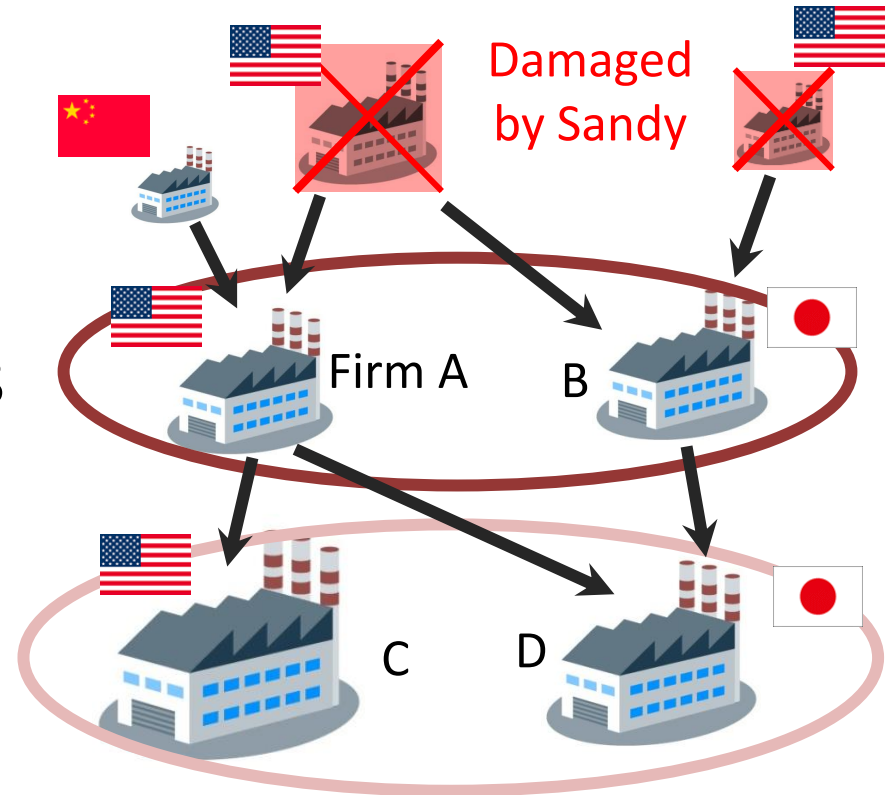
➔ Identify firms directly damaged by Sandy using firm address



Source: National Hurricane Center,
<http://www.nhc.noaa.gov/outreach/presentations/Sandy2012.pdf>

Network Measures

- #/dummy of direct links with damaged suppliers
 - $A = 1; B = 2; C = D = 0$
- #/dummy of indirect links with damaged suppliers in 2 steps
 - $C = 1; D = 2$



Network Measures

Degree centrality

- Total # of supply chain partners

PageRank

- Centrality incorporating centrality of partners

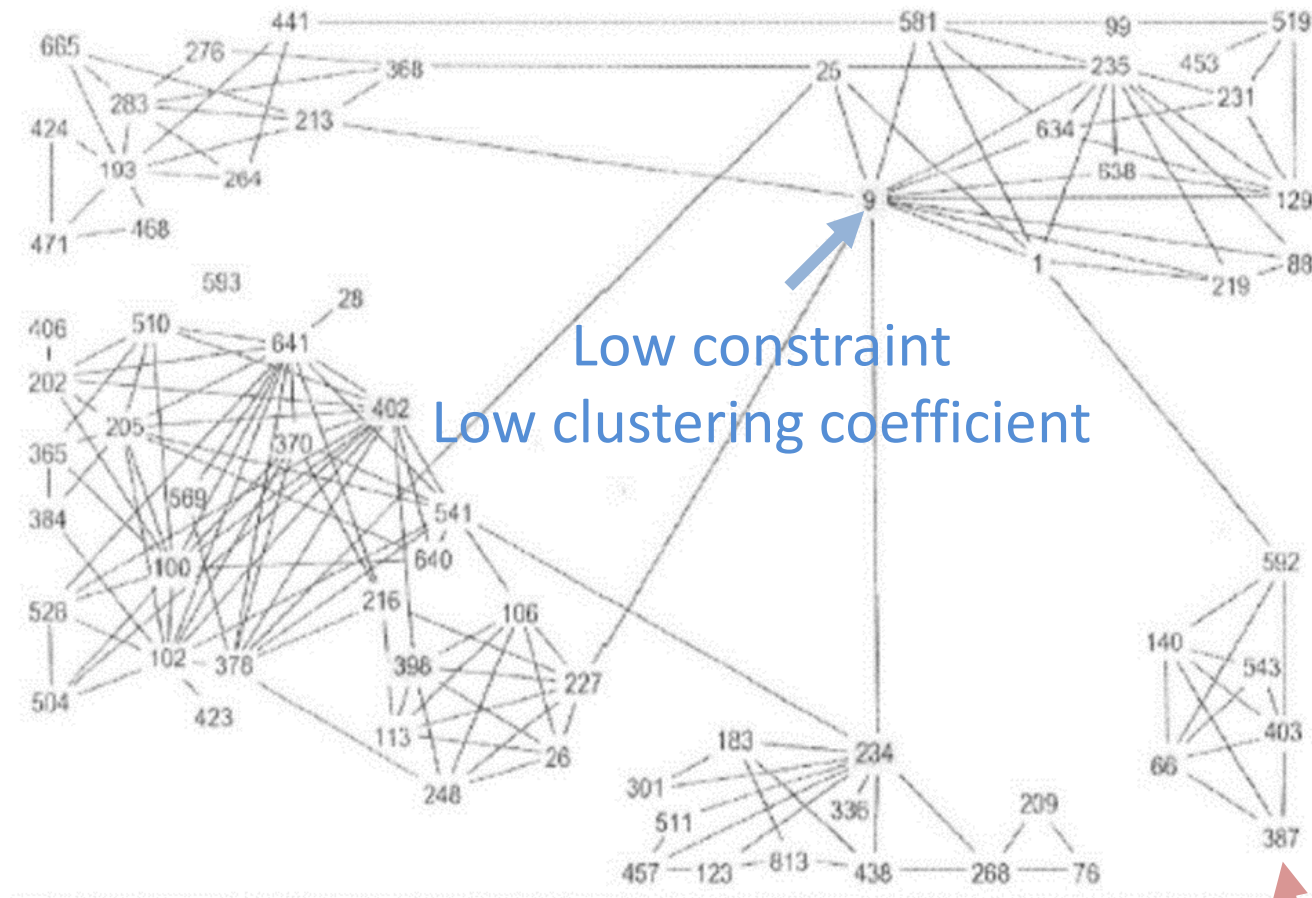
“Constraint” of Burt (1992)

- Similar to HHI for agglomeration
- Small when partners are diversified

Local clustering coefficient

- Measure of density of partners

Example: Employees' network in a company



Low constraint
Low clustering coefficient

High constraint
High clustering coefficient

Summary Statistics

Variable	Mean	S.D.	Min.	Med.	Max
Links with supplier in 2011					
# of suppliers	6.640	14.653	0	3	233
# of domestic suppliers	3.456	10.027	0	1	189
# of foreign suppliers	2.238	5.892	0	1	133
# of suppliers in 2 steps	80.97	157.5	0	11	1341
# of domestic suppliers in 2 steps	39.455	93.812	0	3	879
# of foreign suppliers in 2 steps	36.530	71.330	0	3	602
Links with damaged suppliers in 2011					
# of links with damaged suppliers	0.381	1.298	0	0	24
-- in logs	0.180	0.427	0	0	3.219
Dummy	0.186	0.389	0	0	1
# of 2-step links with damaged suppliers	4.640	11.053	0	0	110
-- in logs	0.867	1.157	0	0	4.710
Dummy	0.452	0.498	0	0	1
# of shareholding links with damaged suppliers	0.002	0.047	0	0	1
-- in logs	0.002	0.032	0	0	0.693
Dummy	0.002	0.047	0	0	1
# of patent application links with damaged suppliers	0.001	0.033	0	0	1
-- in logs	0.001	0.023	0	0	0.693
Dummy	0.001	0.033	0	0	1

Summary Statistics

Variable	Mean	S.D.	Min.	Med.	Max
Other networks measures in 2011					
Burt's constraint	0.189	0.172	0.005	0.126	1
Local clustering coefficient	0.058	0.127	0	0.010	1
PageRank	0	0	0	0	0.003
Firm pre-disaster attributes					
Sales growth from 2006 to 2011	0.124	0.313	-0.598	0.077	10.111
Sales per worker in 2011	1046	13844	2	282	496205
-- in logs	5.701	1.050	0.412	5.644	13.115
# of workers in 2011	12320	52542	3	2555	2200000
-- in logs	7.758	1.931	1.099	7.846	14.604
Value of total assets in 2011	4674462	14486913	1156	927936	270441984
-- in logs	13.708	1.893	7.053	13.741	19.416
Firm age	33.453	30.897	6	22	347

Benchmark Results: # of Links

	(1)	(2)	(3)	(4)
	Dependent variable:			
	Sales growth 2011-12		Sales growth 2011-13	
# of links with damaged suppliers (log)	-0.0458*	-0.0814***	-0.0108**	-0.00965**
	(0.0235)	(0.0209)	(0.00416)	(0.00419)
-- * non-US dummy		-0.00962		-0.0162
		(0.0505)		(0.0157)
# of 2-step links with damaged suppliers (log)	-0.0139	-0.0185	-0.00332	-0.00816*
	(0.0157)	(0.0247)	(0.00490)	(0.00434)
-- * non-US dummy		-0.0172		0.00435
		(0.0222)		(0.00748)
Constraint	0.0445	0.0392	0.0132	0.0173
	(0.0698)	(0.0672)	(0.0192)	(0.0217)
Local clustering coefficient	-0.165**	-0.167**	-0.0845***	-0.0878***
	(0.0715)	(0.0800)	(0.0184)	(0.0175)
PageRank	278.2	246.7	83.99**	81.82*
	(183.4)	(182.7)	(33.17)	(43.29)

S.E. in (). *: $p < 0.1$, **: $p < 0.05$, ***: $p < 0.01$

Benchmark Results

Propagation of negative shocks to direct customers

	Dependent variable:			
	Sales growth 2011-12		Sales growth 2011-13	
# of links with damaged suppliers (log)	-0.0458*	-0.0814***	-0.0108**	-0.00965**
	(0.0235)	(0.0209)	(0.00416)	(0.00419)
-- * non-US dummy		-0.00962		-0.0162
		(0.0505)		(0.0157)
# of 2-step links with damaged suppliers (log)	-0.0139	-0.0185	-0.00332	-0.00816*
				(0.00434)
-- * non-US dummy				0.00435
				(0.00748)
Constraint				0.0173
				(0.0217)
Local clustering coefficient				0.0878***
				(0.0175)
PageRank	278.2	246.7	83.99**	81.82*
	(183.4)	(182.7)	(33.17)	(43.29)

No difference b/w effects on US and non-US customers
 ➔ International propagation is similar to intra-nation.

S.E. in (). *: $p < 0.1$, **: $p < 0.05$, ***: $p < 0.01$

Benchmark Results: # of Links

	(1)	(2)	(3)	(4)
	Dependent variable:			
	Sales growth 2011-12		Sales growth 2011-13	
# of links with damaged suppliers (log)	-0.0458*	-0.0814***	-0.0108**	-0.00965**
	(0.0235)	(0.0209)	(0.00416)	(0.00419)
-- * non-US dummy		-0.00962		-0.0162
		(0.0505)		(0.0157)
# of 2-step links with damaged suppliers (log)	-0.0139	-0.0185	-0.00332	-0.00816*
	(0.0157)	(0.0247)	(0.00490)	(0.00434)
-- * non-US dummy		-0.0012		0.00435
Constraint				
Local clustering coefficient	-0.165**	-0.167**	-0.0845***	-0.0878***
	(0.0715)	(0.0800)	(0.0184)	(0.0175)
PageRank	278.2	246.7	83.99**	81.82*
	(183.4)	(182.7)	(33.17)	(43.29)

Propagation of negative shocks to 2-step customers is unclear

S.E. in (). *: $p < 0.1$, **: $p < 0.05$, ***: $p < 0.01$

Benchmark Results: Dummy for Links

	(1)	(2)	(3)	(4)
	Dependent variable			
	Sales growth 2011-12		Sales growth 2011-13	
Dummy for any link with damaged suppliers	-0.0531** (0.0203)	-0.0747*** (0.0179)	-0.0114*** (0.00325)	-0.0125*** (0.00300)
-- * non-US dummy		0.00123 (0.0425)		-0.0115 (0.0133)
Dummy for any 2-step link with damaged suppliers	-0.118*** (0.0400)	-0.119*** (0.0404)	-0.0474*** (0.0118)	-0.0568*** (0.00581)
-- * non-US dummy		0.0117 (0.0410)		0.0269** (0.0131)
Constraint	0.0412 (0.0721)	0.0367 (0.0653)	0.0111 (0.0188)	0.0165 (0.0210)
Local clustering coefficient	-0.176** (0.0789)	-0.181** (0.0887)	-0.0884*** (0.0184)	-0.0937*** (0.0175)
PageRank	214.7* (112.2)	160.8 (105.1)	65.86*** (22.88)	58.70** (28.70)

S.E. in (). *: $p < 0.1$, **: $p < 0.05$, ***: $p < 0.01$

Benchmark Results: Dummy for Links

	(1)	(2)	(3)	(4)
	Dependent variable			
	Sales			
Dummy for any link with damaged suppliers	-0.053*			
	(0.020)			
-- * non-US dummy		0.0012		-0.0115
		(0.0425)		(0.0133)
Dummy for any 2-step link with damaged suppliers	-0.118***	-0.119***	-0.0474***	-0.0568***
	(0.0400)	(0.0404)	(0.0118)	(0.00581)
-- * non-US dummy		0.0117		0.0269**
		(0.0410)		(0.0131)
Constraint				
Local clustering coefficient				
	(0.0765)	(0.0687)	(0.0184)	(0.0175)
PageRank	214.7*	160.8	65.86***	58.70**
	(112.2)	(105.1)	(22.88)	(28.70)

Propagation to indirect customers is now clear

Propagation to indirect US customers > non-US customers

S.E. in (). *: $p < 0.1$, **: $p < 0.05$, ***: $p < 0.01$

Results: Multi-level Network

	(1)	(2)	(3)	(4)
	Dependent variable			
	Sales growth 2011-12		Sales growth 2011-13	
	#	Dummy	#	Dummy
#/dummy of links with damaged suppliers (log)	-0.0507**	-0.056***	-0.012***	-0.013***
	(0.0231)	(0.0185)	(0.00350)	(0.00328)
-- associated with shareholding ties	0.201***	0.117***	0.0197	0.00819
	(0.0499)	(0.0320)	(0.0131)	(0.00889)
-- associated with R&D ties	-0.275	-0.263*	-0.101***	-0.088***
	(0.165)	(0.133)	(0.0247)	(0.0161)

S.E. in (). *: $p < 0.1$, **: $p < 0.05$, ***: $p < 0.01$

Results: Multi-level Network

	(1)	(2)	(3)	(4)
	Dependent variable			
	Sales growth 2011-12	Sales growth 2011-12	Sales growth 2011-13	Sales growth 2011-13
	#	Dummy	#	Dummy
#/dummy of links with damaged suppliers (log)	-0.0507** (0.0231)	-0.056*** (0.0185)	-0.012*** (0.00350)	-0.013*** (0.00328)
-- associated with shareholding ties	0.201*** (0.0499)	0.117*** (0.0320)	0.0197 (0.0131)	0.00819 (0.00889)
-- associated with R&D ties	-0.275 (0.165)	-0.263* (0.135)	-0.101*** (0.0321)	-0.088*** (0.0321)

Shareholding ties
alleviate propagation

R&D ties amplify
propagation

S.E. in (). *: $p < 0.1$, **: $p < 0.05$, ***: $p < 0.01$

Results: Network Diversity and Density

	(1)	(2)	(3)	(4)
	Dependent variable			
	Sales growth 2011-12		Sales growth 2011-13	
Dummy for any link with damaged suppliers	-0.104**	-0.0269*	-0.0369***	-0.000470
	(0.0468)	(0.0154)	(0.00858)	(0.00562)
-- * constraint	0.384		0.196***	
	(0.267)		(0.0662)	
-- * local clustering coefficient		-0.451*		-0.196**
		(0.256)		(0.0821)
Dummy for any 2-step link with damaged suppliers	-0.112***	-0.118***	-0.0517***	-0.0523***
	(0.0383)	(0.0405)	(0.0115)	(0.0141)
-- * constraint	-0.0275		0.0198	
	(0.0749)		(0.0636)	
-- * local clustering coefficient		0.0198		0.111
		(0.0926)		(0.0777)
Constraint	0.0280	0.0382	-0.00287	0.0101
	(0.0631)	(0.0693)	(0.0174)	(0.0184)
Local clustering coefficient	-0.174**	-0.147*	-0.0876***	-0.103***
	(0.0746)	(0.0773)	(0.0198)	(0.0277)

Results: Network Diversity and Density

			(3)	(4)
			Control variable	
			Sales growth 2011-13	
Dummy for any link with damaged suppliers	(0.0468)	(0.0000)	-0.0369***	-0.000470
-- * constraint	0.384		0.196***	
	(0.267)		(0.0662)	
-- * local clustering coefficient		-0.451*		-0.196**
		(0.256)		(0.0821)
Dummy for any 2-step link with damaged suppliers	-0.112***	-0.119***	-0.0517***	-0.0523***
-- * constraint			0.15)	(0.0141)
			0.98	
-- * local clustering coefficient			0.36)	0.111
		(0.0926)		(0.0777)
Constraint	0.0280	0.0382	-0.00287	0.0101
	(0.0631)	(0.0693)	(0.0174)	(0.0184)
Local clustering coefficient	-0.174**	-0.147*	-0.0876***	-0.103***
	(0.0746)	(0.0773)	(0.0198)	(0.0277)

Diversity of partners
→ ↑ propagation effects

Density of partners
→ ↑ propagation effects

Summary and Discussion

Propagation to direct US customers

\approx to non-US customers > 0

- US inputs are as specific to non-US customers as to US customers.

Propagation to 2-step domestic customers

$>$ to 2-step foreign customers ≈ 0

- Propagation to foreign countries dies out sooner than within the US.

Summary and Discussion

Propagation through supply chains is

- **alleviated by shareholding ties**
 - Suppliers allocate more supplies to affiliated customers through ownership relations.
- **amplified by R&D ties**
 - Inputs developed by R&D collaboration are more specific.

Summary and Discussion

Propagation through supply chains is amplified by

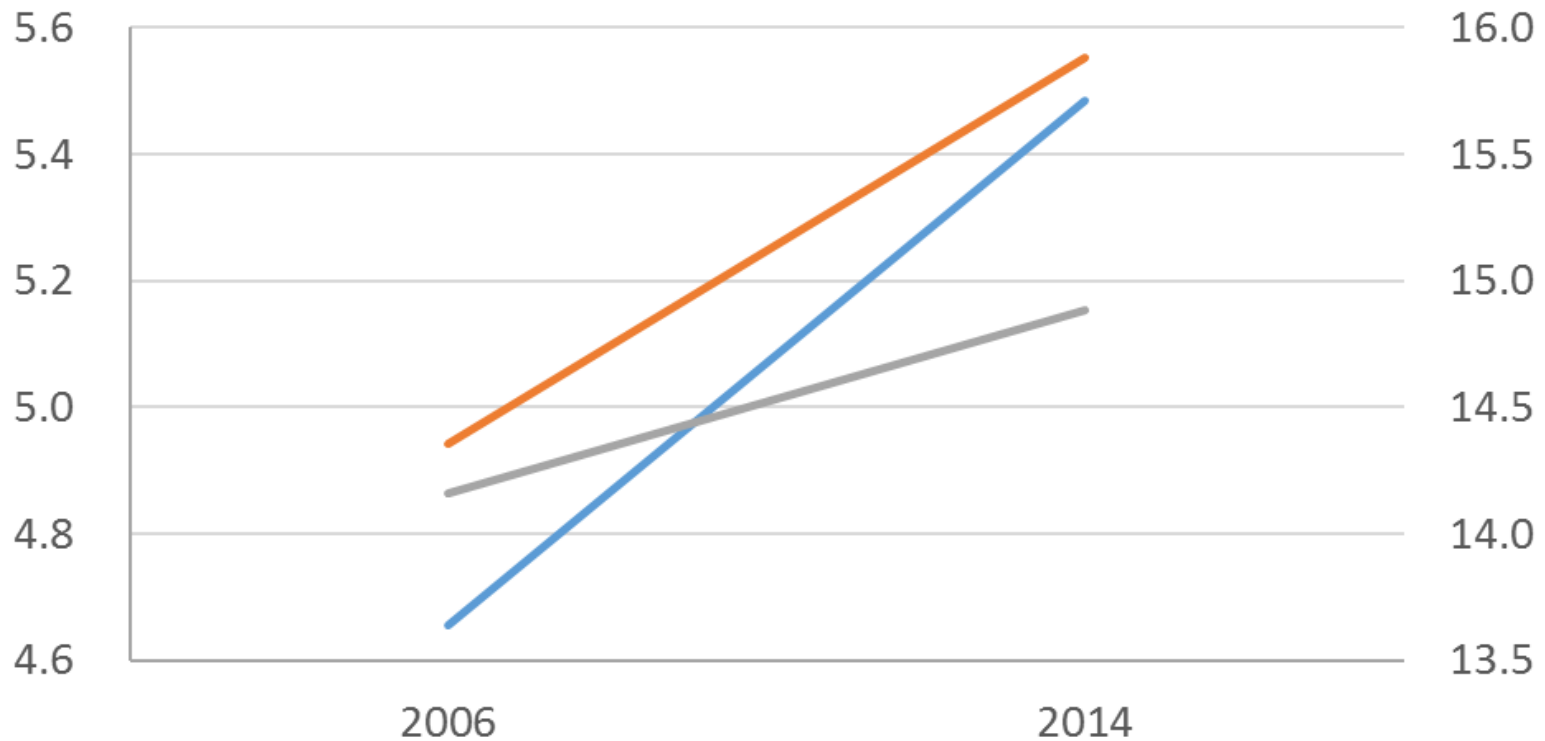
- **diversity of supply chain partners**
 - More likely to be connected indirectly with damaged suppliers in many steps.
- **density of supply chain partners**
 - Firms within a firm group affect each other.

Policy Implications

- International supply chains are well developed in Asia.
- Asia should prepare for possible propagation of negative shocks due to natural and man-made disasters through supply chains.
 - Tentative financial support to customers of damaged firms in the wake of disasters
 - Promote diversity in supply chain partners
 - Promote business continuity plans (BCPs) to small and medium enterprises (SMEs)

(Cole et al. 2015)

Average Characteristics of Top 5 Japanese Automobile Manufacturers

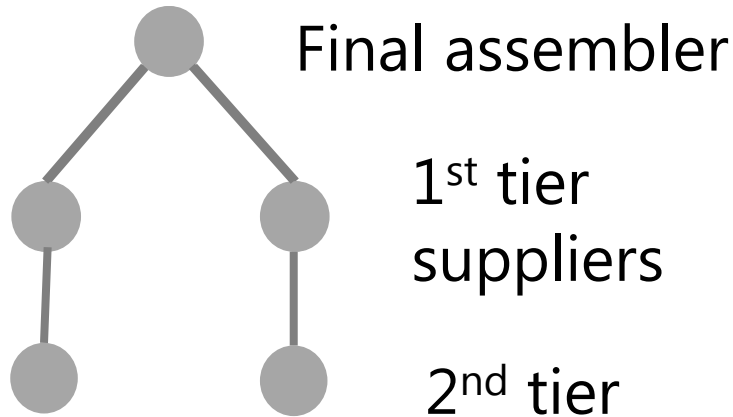


- # of suppliers within 3 steps (10,000)
- Share of actual ties between 1st-tier suppliers in all possible pairs (‰)
- Average # of buyers of 1st-tier suppliers (right scale)

Data source: Tokyo Shoko Research

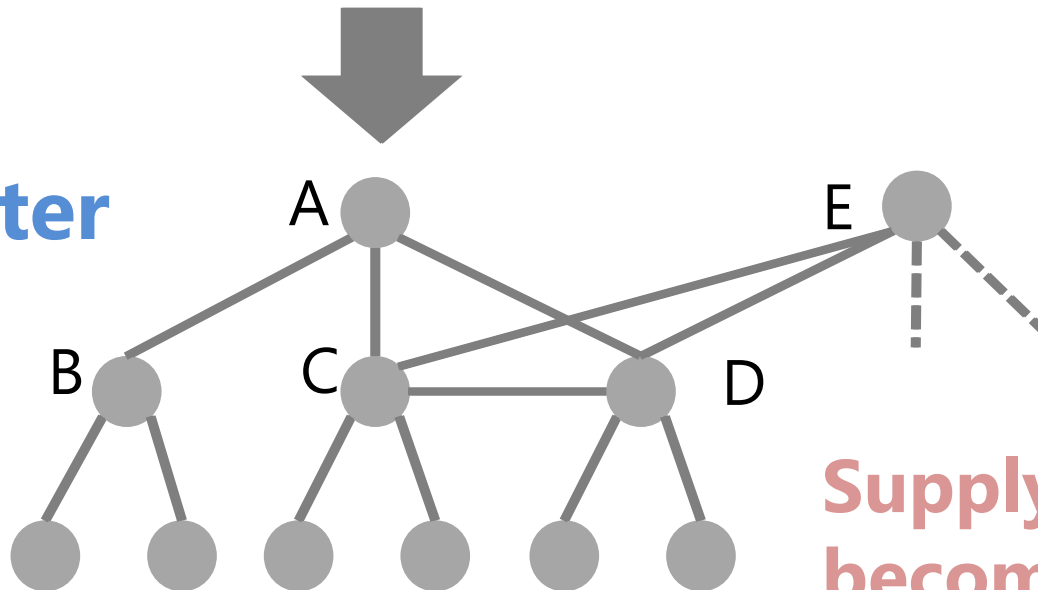
Illustration of Changes in Supply Chains

Before



When C is hit, it may be replaced with D.

After



When A is hit, C can still survive because of demand from E.

Supply chains have become more resilient.

Japanese firms learned from Great East Japan earthquake in 2011

- Toyota completed surveys of supply chains to get information on 130,000 direct/indirect suppliers
 - ➔ Database of suppliers (RESCUE)
 - Visualize supply chains for each part
 - List up vulnerable firms in the wake of disasters

Fujimoto, 2016, Toyota way in procurement and supply chain management, MMRC Discussion Paper, No. 487, the University of Tokyo. http://merc.e.u-tokyo.ac.jp/mmrc/dp/pdf/MMRC487_2016.pdf

- ↑ preparation of BCPs for SMEs from 9 to 12%

Hamaguchi, 2013, RIETI Policy Discussion Paper, No. 13-P-001.

BCPs were effective in GEJ earthquake.

Table 6. Dependent Variable: Number of Days of Stopped Operations

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Quake Damage	1.47*** (0.045)	1.47*** (0.046)	1.46*** (0.045)	1.47*** (0.044)	1.47*** (0.045)	1.46*** (0.039)	1.40*** (0.040)
Tsunami Damage	2.18*** (0.090)	2.19*** (0.094)	2.18*** (0.089)	2.18*** (0.090)	2.18*** (0.090)	2.18*** (0.094)	2.13*** (0.11)
Transport_Subs_Policy		0.84 (0.15)				0.73 (0.21)	0.43** (0.17)
Prodn_Subs_Policy			1.05 (0.089)			1.28 (0.21)	0.79 (0.15)
BusinessContinuityPlan				0.87 (0.087)		0.87 (0.086)	0.64*** (0.098)
DiversifiedPartSuppliers					0.88 (0.12)	0.90 (0.12)	1.06 (0.18)
Prodn_subs_policy*Quake Damage							1.50* (0.31)
BusinessContinuityPlan*Tsunami Damage							0.71*** (0.093)
Sales (pre quake)	0.98 (0.018)	0.98 (0.018)	0.98 (0.018)	0.98 (0.018)	0.98 (0.018)	0.99 (0.018)	0.98 (0.017)
NumTradingPartners	0.99 (0.074)	0.99 (0.074)	1.00 (0.075)	0.99 (0.075)	0.99 (0.075)	1.00 (0.075)	1.01 (0.075)
Single_Product	0.94 (0.061)	0.94 (0.061)	0.94 (0.061)	0.94 (0.061)	0.94 (0.061)	0.93 (0.060)	0.94 (0.060)
Overseas_Dum	0.65*** (0.092)	0.65*** (0.091)	0.65*** (0.092)	0.66*** (0.096)	0.65*** (0.091)	0.65*** (0.094)	0.66*** (0.093)
Observations	913	913	913	913	913	913	913

Cole, et al. (2015), The Effectiveness of Pre-Disaster Planning and Post-Disaster Aid: Examining the impact on plants of the Great East Japan Earthquake, RIETI Discussion Paper, No. 15-E-097