Cascading Innovation

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Introduction

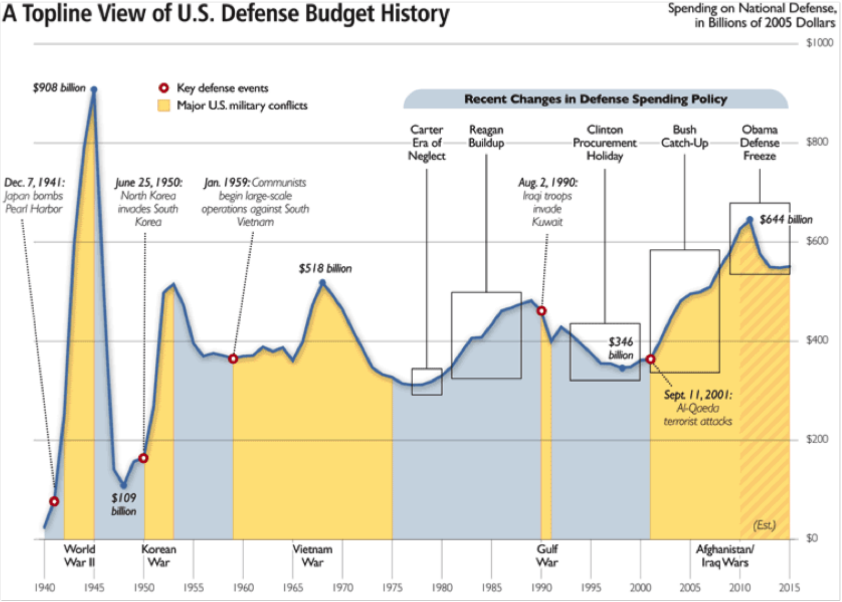
- A big focus of growth research has been non-pecuniary **knowledge spillovers** (eg: Griliches (1982), Jaffee (1986) Bloom et al (2013)).
- Another focus is (pecuniary) **demand-led innovation**:
  - 'The amount of invention is governed by the extent of the market', Schmookler(1966), *Invention and Economic Growth.*
- This has yielded a number of **market size** studies: Health (Acemoglu and Linn, 2004; Finkelstein, 2004), Environment (Aghion et al, 2012), Energy (Popp 2002).

Role of the State

- Government-led innovation?
  - Government-led expansions of market size may have been instrumental for innovation
    - "Every technology that makes the iPhone so 'smart' was government funded: the Internet, GPS, its touch-screen display and the voice-activated SIRI" [Mazzucato, 2013 "*The Entrepreneurial State*"]
- Defense-led innovation?
  - Defense spending has had a massive role in US public spending:
    - 15-20% total government outlays
    - 20% of post-war R&D (30% in 1950s)
    - Major policy tool: Compare $6.5 billion annually for R&D tax credit versus $16 billion of military R&D alone.

This paper.

- We address the market size question using a (firm-level) **production network** approach (eg: Atalay et al (2011), Acemoglu et al (2012), Carvalho(2014), Baqaee and Farhi (2017)).
- **Basic idea**: Trace the transmission of defense spending shocks through the supply chain. Are there credible **'cascading market size'** effects on innovation?
- **Implementation**: A monstrous combination of federal contracts, patents and Compustat production network data. Best illustrated by example....


A Topline View of U.S. Defense Budget History
Spending on National Defense, in Billions of 2005 Dollars
$1000
$800
$600
$400
$200
$0
Key defense events
Major U.S. military conflicts
$908 billion
Dec. 7, 1941: Japan bombs Pearl Harbor
June 25, 1950: North Korea invades South Korea
Jan. 1959: Communists begin large-scale operations against South Vietnam
$109 billion
$518 billion
Recent Changes in Defense Spending Policy
Carter Era of Neglect
Reagan Buildup
Clinton Procurement Holiday
Bush Catch-Up
Obama Defense Freeze
Aug. 2, 1990: Iraqi troops invade Kuwait
$346 billion
Sept. 11, 2001: Al-Qaeda terrorist attacks
$644 billion
(Est.)
World War II
Korean War
Vietnam War
Gulf War
Afghanistan/ Iraq Wars
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015

Example - General Dynamics.

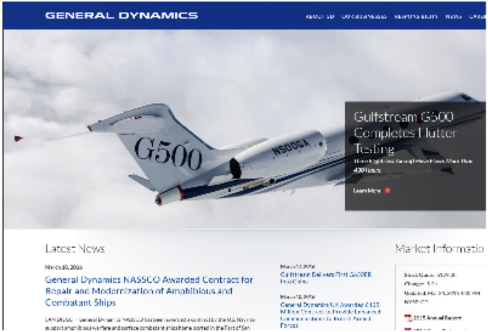


FIGURE: General Dynamics, a major defense contractor

- DoD records: information on all procurement contracts
- General Dynamics is a major DoD contractor during 80s
  - "F-16 Falcon" fighter; "Stinger" surface-to-air missile; "M1 Abrahams" tank
  - DoD records show General Dynamics winning contracts throughout the 80s in each of these categories

Data - Matched Procurement Contracts.

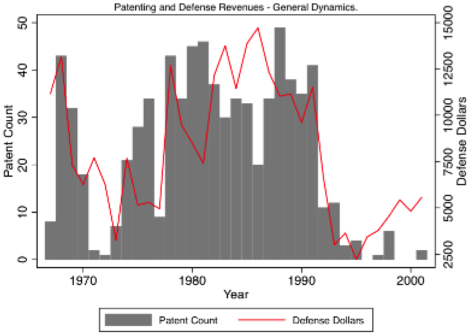


FIGURE: Total defense contracts awarded to General Dynamics and patents issued by firm.

- DoD records: information on all procurement contracts
- General Dynamics is a major DoD contractor during 80s
  - Use Compustat balance sheet data + NBER patent data to look into firm-level innovation outcomes following DoD contracts

Data - Supply Chain

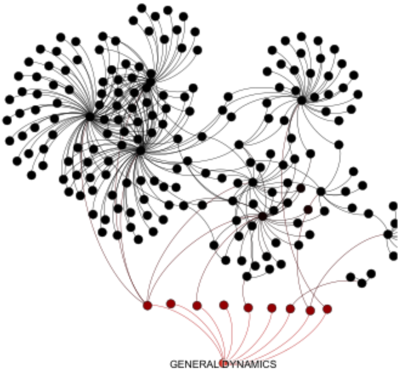


FIGURE: The Supply Chain of General Dynamics in 1990

- Supply Chain & Cascading Innovation
- Financial Accounting Standards Rule No.131: listed firms required to disclose identity of major customers
  - Back out supply chain of each firm in DoD records
  - Use Compustat balance sheet data + NBER patent data to look into innovation outcomes across the supply chain

Shocks to Market Size?

- To parse exogenous shocks we use product-level information on the composition of DoD spending.
- Specifically, the DoD has historically utilised a 4-digit Federal Supply Code (FSC) that is largely consistent from 1966 onwards.
- We use this to define 'DoD product markets' that firms specialise in. Shifts in spending then affect firms through a Bartik-style mechanism..

2-DIGIT LEVEL

Department of Defense

Procurement Coding Manual

	FEDERAL SUPPLY GROUP
	10
Nuclear Ordnance	11
Fire Control Equipment	12
Ammunition & Explosives	13
Guided Missiles	14
Aircraft & Airframe Structural Components	15
Aircraft Components & Accessories	16
Aircraft Launching, Landing, & Ground Handling Equipment	17
Space Vehicles	18
Ships, Small Craft, Pontoons, & Floating Docks	19
Ship & Marine Equipment	20
Railway Equipment	22
Ground Effect Vehicles, Motor Vehicles, Trailers, & Cycles	23
Tractors	24
Vehicular Equipment Components	25
Tires & Tubes	26
Engines, Turbines, & Components	28
Engine Accessories	29
Mechanical Power Transmission Equipment	30
Bearings	31
Woodworking Machinery & Equipment	32
Metalworking Machinery	34
Service & Trade Equipment	35
Special Industry Machinery	36
Agricultural Machinery & Equipment	37

Department of Defense
Procurement Coding Manual

4-DIGIT LEVEL

AIRCRAFT COMPONENTS & ACCESSORIES	(16)
Aircraft Propellers	1610
Helicopter Rotor Blades, Drive Mechanisms, & Components	1615
Aircraft Landing Gear Components	1620
Aircraft Wheel & Brake Systems	1630
Aircraft Hydraulic, Vacuum, & De-Icing System Components	1650
Aircraft Air Conditioning, Heating, & Pressurizing Equipment	1660
Parachutes; Aerial Pick Up, Delivery, & Recovery Systems; & Cargo Tie-Down Equipment	1670
Miscellaneous Aircraft Accessories & Components	1680
NUCLEAR ORDNANCE	(11)
Nuclear Bombs	1105
Nuclear Projectiles	1110
Nuclear Warheads & Warhead Section	1115
Nuclear Depth Charges	1120
Nuclear Demolition Charges	1125
Nuclear Rockets	1127
Conversion Kits, Nuclear Ordnance	1130
Fuzing & Firing Devices, Nuclear Ordnance	1135
Nuclear Components	1140
Explosive & Pyrotechnic Components Nuclear Ordnance	1145
Specialized Test & Handling Equipment, Nuclear Ordnance	1190
Miscellaneous Nuclear Ordnance	1195

Firm Product Specialisation Example

EXAMPLE: GENERAL DYNAMICS PRODUCT SHARES, 1981.

	2-digit Code	Share
Aircraft and Airframe Structural Components	15	0.4324501
Ships, Small Craft, Pontoons, and Floating Docks	19	0.2136508
Guided Missiles	14	0.0919438
R&D (Weapons / Electronics/ Communications)	AC	0.0903228
Weapons	10	0.0667323
Modification of Equipment	K0	0.0134402
Maintenance, Repair, and Rebuilding of Equipment	J0	0.0110186
Support - Professional: Program evaluation/review/development	R4	0.0089637
R&D (Space Transportation)	AR	0.0085547
Maintenance and Repair Shop Equipment	49	0.0074202

(Plus 56 further 2-digit products)

For sample: Num products = 11 (median), 19 (mean)]

Cascading Market Size...

- The twist to the basic Bartik strategy is that we map how the DoD market size shocks affect firms *down the supply chain with no direct relationship to the DoD.*

- Hence, these firms are *removed from the endogeniety concerns* that come up with first-order transmission in Bartik designs.

- The approach also closely captures the indirect 'government-induced innovation' effect that has been long speculated but hard to pin down empirically.

Preview of Results

- Manage to capture clear evidence of firm-to-firm transmission of defense spending shocks. Effects are at least as big the main direct effects of defense sales.
- This 'pecuniary spillover' channel is a separate empirical mechanism to the better known knowledge spillover mechanism.
- Innovation patterns among the 'islands' plausibly fit the hypothesis of high-tech 'general purpose' innovation indirectly created by defense spending.

Overview of Talk

- **Analytical Framework:** Market size and innovation in the simplest supply chain.
- **Data:** How we build these ‘cascading shocks’ and what the pattern looks like.
- **Empirical Strategy and Results:** Simple, clean approach to modelling ‘sparse’ network shocks.

Analytical Framework (1)

- 3 agents in the simplest supply chain:
  - Final consumer: downward sloping demand curve
  - Downstream final goods producer,
  - Upstream intermediate goods suppliers (Cournot competitors)
- Both downstream and upstream firms:
  - Choose quantities produced in order to maximize profits
  - Choose how much to spend on (marginal) cost-reducing innovation efforts
- Key comparative statics of interest:
  - Response of quantities produced, innovation efforts and profits
  - Across the supply chain
  - Following outward shift of final demand curve

Analytical Framework (2)

- Key result: Cascading Innovation
  - Increasing the extent of the final demand good's market $\rightarrow$ worthwile to engage in cost-reducing innovation *at all levels of the supply chain*

- These are simple market size mechanics:
  - *Downstream:* Downstream producer faces (the traditional) direct market size effect + cost reduction effect on its intermediate input (given upstream innovation)
  - *Upstream:* Upstream producer faces a (derived) demand increase: increasing the size of the final demand goods' market leads to *recursive* market size effects up the supply chain.
    - This is a novel *pecuniary* spillover channel.

Data - US Defense Procurement Data.

- DoD Military Prime Contracts Files
  - 1966-2003: via National Archives
  - supplemented with Federal Procurement Data System 2003-2010
- Universe of DoD military contracts above $10,000.
  - Transaction amount, contractor name, location of work, dates of action, estimated completion date, contracting office within DoD.
  - Also: detailed Federal Supply product codes + weapon system codes.

Data - Firm-Level Outcomes.

- Match procurement winners to firms in COMPUSTAT.
- Matched via contractor name + ownership structure
  - String-based name matching + DUNS + manual
  - Getting about 75-80% total dollar value of DoD contracts, up to 95% for R&D contracts.
  - Obtain Sales and R&D outcomes + host of covariates for 1966 onwards
- Merge in NBER Patents Database:
  - Obtain Patent counts, Citations at firm level
  - 1966- 2007 (baseline sample years)
  - Baseline sample: only firms that have ever patented

Data - Supply Chain Data.

- Financial Accounting Standards Rule No.131:
  - US Publicly listed firms are required to disclose the identity of their major customers (10% of the seller's revenues).
  - They often disclose the share as well: we only work with these observations.
- Information retrieved from SEC fillings:
  - Available in Compustat Customer Segment File.
  - String-based name matching + manual.
  - 1977-2007 (annual).

Data - Compustat Production Network.

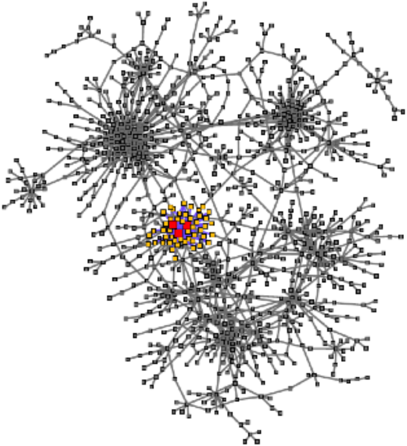


Fig. 2. Buyer–supplier network in 2006. GM, Ford, and Chrysler are colored red. Their suppliers are colored orange. All other firms are gray.

[From Atalay et al, 2012, PNAS]

Defining Cascading Shocks.

- Construct 'derived demand' from DoD contracts for supplier i of firm k at time t:
  - θ_{ik}: share of inputs that customer k purchases from supplier i.
  - Amount of defense dollars from customer k to its supplier i:

$$c_{ikt} = \theta_{ik} d_{kt}$$

  - Supplier receives these 'cascading' shocks across multiple purchasers of its goods. Aggregate across the K customers of each supplier i to get the full cascading shock:

$$c_{it}^{K} = \sum_{k=1}^{K} c_{ikt}$$

- Premise: supply chain relations are "sticky".

Defining Market Size Shocks.

- Here, we need the historical within-firm product shares of the customer firms:

$$\phi_{kl,t-5} = \frac{d_{kl,t-5}}{\sum_{l=1}^{L} d_{kl,t-5}} \tag{1}$$

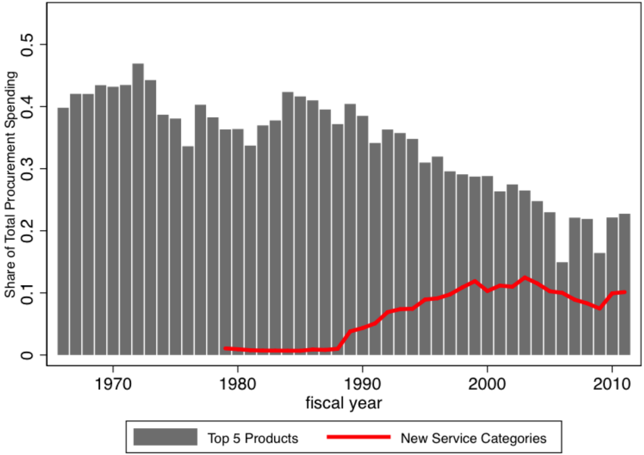
where l denotes DoD product code and k is customer firm.

- Hence total market size for firm k in period t calculated as:

$$m_{kt} = \sum_{l=1}^{L} \phi_{kl,t-5} D_{lt} \tag{2}$$

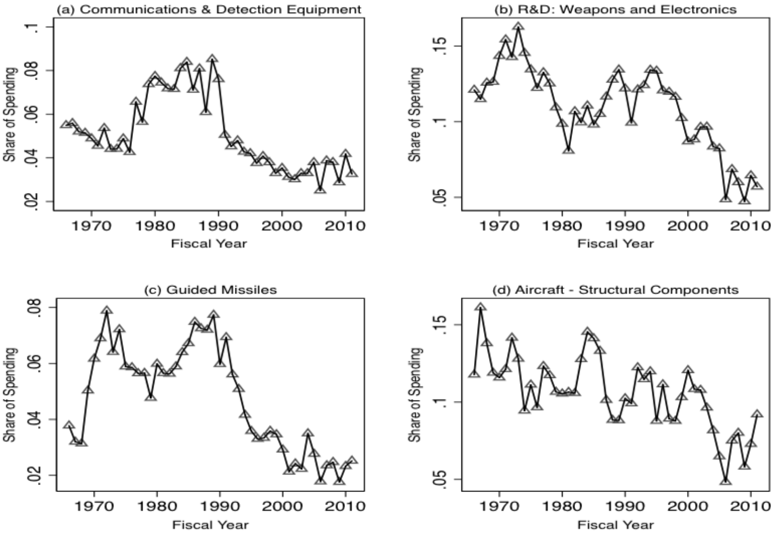
where D_{lt} is total DoD spending on product l. This variation at the k level then gets **transmitted through the supply chain network via θ_{ik} the input share relationships.**

Figure 2: Product Shares in Total Procurement Spending, 1966-2011.



Notes: This figures shows the share of "Top 5" products in total procurement spending over time. The Top 5 have been calculated based on shares in the 1966-1976 period and include the categories: Defense, Weapons & Electronics R&D (AC); Aircraft and Airframe Structural Components (15); Guided Missiles (14); Ammunition and Explosives; and Communications, Detection and Coherent Radiation Equipment (58). (2-digit FSC classifications given in parentheses). The New Service Categories represent new 2-digit FSC groups introduced in 1979 and 1989. These include Social and Economic Science R&D (FSC groups AB, AE, AF, AL, AQ, B5 and R5); Architecture and Engineering Services (FSC groups R1, C1, C2); Data Processing and Communications (D3); Environmental Services (F0, F1, F9) ; Equipment and Materials Testing (H2), Lease and Rental of Facilities (X2); Medical Services (Q5), and Quality Control Services (H1, H9)

Figure 3: Changes in Federal Supply Code (FSC) 2-digit Product Shares.



Empirical Model (1)

- We have a generic outcome equation:

$$y_{it} = \alpha_i + \beta c_{it}^K + \delta d_{it} + X_{it}' \lambda + \tau_t + \epsilon_{it} \tag{3}$$

where y_{it} is patents, sales or R&D; c_{it}^K are cascading sales shocks; d_{it} are direct defense sales receipts.

- Main issue is that c_{it}^K and d_{it} are sparse, with a mix of intensive and extensive margin shifts in sales shocks.

Empirical Model (2)

- Use discrete indicators to measure different levels of sales shocks:

$$y_{it} = \alpha_i + \sum_{q=1}^{Q} \beta^q c_{it}^{K,q} + \sum_{q=1}^{Q} \delta^q d_{it}^q + X_{it}'\lambda + \tau_t + \epsilon_{it} \qquad (4)$$

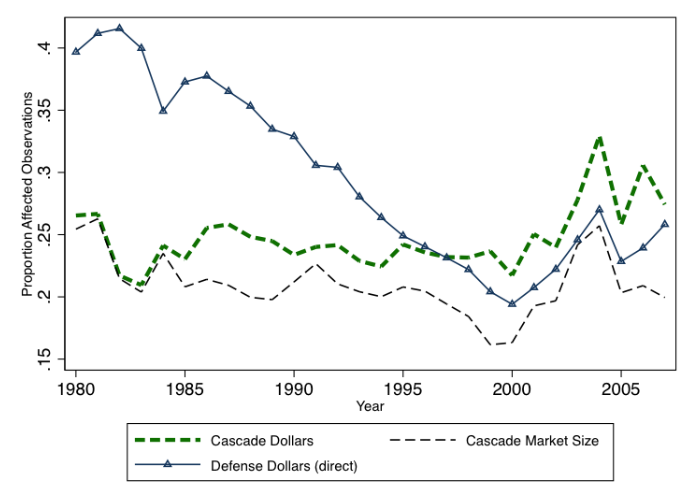
  where where q indexes the quantile and we set all the instances of $c_{it}^K = 0$ and $d_{it} = 0$ as the default categories.

- Basic logic of this 'discretized shock' approach can be extended to indicators for the layer of the supply chain, market size shocks, or type of firm.

Table 1: Characteristics of Compustat Supplier Sample, 1976-2007

Variable	Value	Std. Dev.
(A) Main Variables (mean)		
Patent Count	11.3	80.7
Citation Count	81.0	598.6
Employment (in 1000s)	5.9	(18.8)
Employment (median)	0.6	-
Sales (in $1000s)	1,445	5,5680
R&D	73.1	358.0
(B) Sales Shocks (frequency)		
Cascade Dollars	0.234	-
Defense Dollars	0.287	-
"Island" Cascade Dollars	0.095	-
Cascade Market Size	0.195	-
(C) Link Structure		
Distinct Supplier-Customer pairs	6,976	-
Mean Link Duration (years)	3.1	3.1
Suppliers per Customer (mean)	18.0	98.3
Suppliers per Customer (median)	3.0	-
(Customer Purchases / Supplier Sales) share (mean)	0.201	0.186
(Customer Purchases / Supplier Sales) share (median)	0.146	-
Number of Customer Firms	1,414	-
Number of Supplier Firms	2,633	-

Figure 4: Frequency of Non-Zero Sales Shocks, Supplier Sample.



Notes: This figure shows the frequency of non-zero observations for Cascading Dollars, Defense Dollars and Cascade Market Size, defined as per the frequency definition of Table 1. That is, this plots the proportion of non-zero observations for each variable where we normalise by the total number of supplier observations in a given year. The sample used is the N = 38,580 sample with 2,633 unique supplier firms. The plot starts in 1980 to allow for the lags in the definition of the market size variable to settle in.

BASELINE RESULTS

How do the effects of cascade shocks versus direct defense sales shocks compare?

Table 2: Cascade Effects for Suppliers, 1976-2007

	(1) ln(Patent Count)	(2) ln(Sales)	(3) ln(R&D)
(A) Continuous Model			
ln(Cascade Defense Sales)$_{t-1}$	0.019***	0.028***	0.025***
	(0.004)	(0.005)	(0.006)
ln(Direct Defense Sales)$_{t-1}$	0.029***	0.050***	0.033***
	(0.004)	(0.006)	(0.006)
(B) Discrete Model			
Cascade Shock$_{t-1}$	0.081***	0.167***	0.088***
	(0.018)	(0.028)	(0.029)
Direct Defense Shock$_{t-1}$	0.138***	0.258***	0.145***
	(0.022)	(0.031)	(0.032)
Number of Firms	2,633	2,633	2,226
Number of Observations	38,580	38,580	27,862

Notes: Standard errors clustered by firm in parentheses. All specifications include firm fixed effects and SIC4-year fixed effects. ln(Cascade Dollars)$_{t-1}$ is the log of all sales dollars received by the supplier via cascading customer purchases. ln(Defense Dollars) is the log of dollars received by the supplier via directly awarded prime defense contracts. The variable Cascade Shock$_{t-1}$ is an indicator variable for instances where (Cascade Defense Sales$_{t-1} > 0$). The variable Direct Defense Shock$_{t-1}$ is an indicator variable for instances where (Direct Defense Sales$_{t-1} > 0$).

TYPE OF SHOCK

Effects by financial size of shock and level of cascade?

Table 3: Cascade Effects by Size of Shock and Supply Chain Level

	(1) ln(Patent Count)	(2) ln(Sales)	(3) ln(R&D)
(A) Size of Shock			
Cascade Shock$_{t-1}$ - Below Median	0.035*	0.149***	0.031
	(0.019)	(0.034)	(0.030)
Cascade Shock$_{t-1}$ - Above Median	0.147***	0.195***	0.180***
	(0.028)	(0.034)	(0.043)
Direct Defense Shock$_{t-1}$ - Below Median	0.092***	0.186***	0.093***
	(0.021)	(0.027)	(0.030)
Direct Defense Shock$_{t-1}$ - Above Median	0.259***	0.447***	0.294***
	(0.037)	(0.052)	(0.053)
(B) Supply Chain Level			
Cascade Shock$_{t-1}$ - Upper Level	0.072***	0.170***	0.063**
	(0.019)	(0.029)	(0.030)
Cascade Shock$_{t-1}$ - Lower Level	0.082***	0.144***	0.052
	(0.029)	(0.037)	(0.040)
Direct Defense Shock$_{t-1}$	0.139***	0.261***	0.146***
	(0.022)	(0.031)	(0.032)
Number of Firms	2,633	2,633	2,226
Number of Observations	38,580	38,580	27,862

Table A1: Cascade Effects - Tercile Models (Size of Shock)

	(1) ln(Patent Count)	(2) ln(Sales)	(3) ln(R&D)
Tercile 1 Cascade Shock$_{t-1}$	0.041**	0.153***	0.001
	(0.021)	(0.039)	(0.032)
Tercile 2 Cascade Shock$_{t-1}$	0.057**	0.168***	0.123***
	(0.024)	(0.037)	(0.046)
Tercile 3 Cascade Shock$_{t-1}$	0.181***	0.195***	0.197***
	(0.038)	(0.040)	(0.047)
Tercile 1 Direct Defense Shock$_{t-1}$	0.052**	0.145***	0.060**
	(0.021)	(0.026)	(0.029)
Tercile 2 Direct Defense Shock$_{t-1}$	0.188***	0.315***	0.195***
	(0.031)	(0.039)	(0.046)
Tercile 3 Direct Defense Shock$_{t-1}$	0.341***	0.564***	0.393***
	(0.048)	(0.069)	(0.068)
Number of Firms	2,633	2,633	2,226
Number of Observations	38,580	38,580	27,862

DECOMPOSING DISCRETE SHOCKS

Do we see effects among 'island' firms with no direct DoD link?

Table 4: Cascade Effects - Decomposing Discrete Shocks

	ln(Patent Count)		ln(Sales)		ln(R&D)	
	(1)	(2)	(3)	(4)	(5)	(6)
Cascade Shock$_{t-1}$	0.081***		0.167***		0.088***	
	(0.018)		(0.028)		(0.029)	
Island Shock$_{t-1}$		0.115***		0.268***		0.128***
		(0.025)		(0.049)		(0.045)
Non-Overlapping Shock$_{t-1}$		0.105***		0.151***		0.063
		(0.028)		(0.040)		(0.044)
Overlapping Shock$_{t-1}$		0.009		0.036		0.058
		(0.033)		(0.035)		(0.046)
Direct Defense Shock$_{t-1}$	0.138***	0.162***	0.258***	0.288***	0.145***	0.146***
	(0.022)	(0.024)	(0.031)	(0.034)	(0.032)	(0.036)
Number of Firms	2,633	2,633	2,633	2,633	2,226	2,226
Number of Observations	38,580	38,580	38,580	38,580	27,862	27,862

LOOKING AT THE ISLANDS.

Market size versus technology spillovers?

Table 5: Cascade Effects - Market Size vs Technological Spillovers

	ln(Patent Count)			ln(R&D)		
	(1)	(2)	(3)	(4)	(5)	(6)
Cascade Shock$_{t-1}$	0.111***			0.132***		
	(0.028)			(0.051)		
Cascade Market Size Shock$_{t-1}$		0.136***	0.135***		0.134**	0.134**
		(0.032)	(0.032)		(0.056)	(0.056)
ln(Tech Spill)$_{t-1}$			0.310**			1.495***
			(0.153)			(0.560)
Number of Firms	817	817	817	698	698	698
Number of Observations	9,895	9,895	9,895	7,383	7,383	7,383

Technological Distance

- What's the composition of the innovation in the cascade? Is defense spending inducing technological development in 'general purpose' areas?
- We break down the 3-digit US patent tech classes (N=419) and calculate shares among different firm groups.
- These are a) Top 50 direct contractors; b) Smaller contractors who are suppliers; and c) 'Island' suppliers.

Figure 5a - Technological Distance, Small Contractors versus Top Contractors.

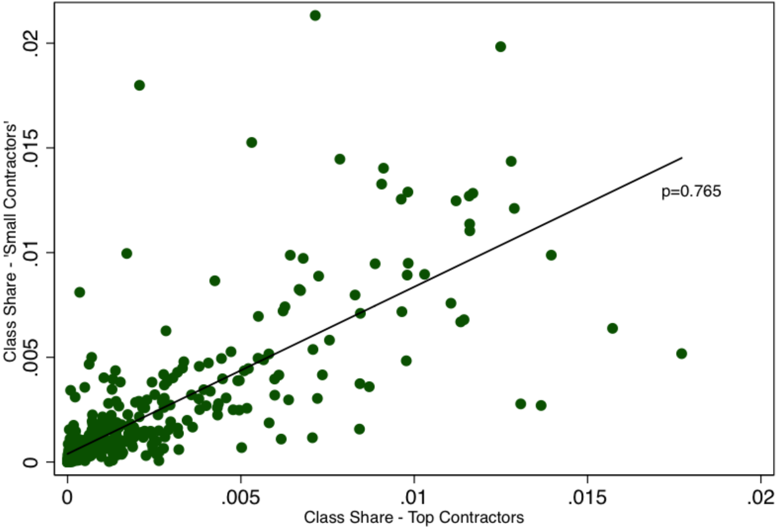
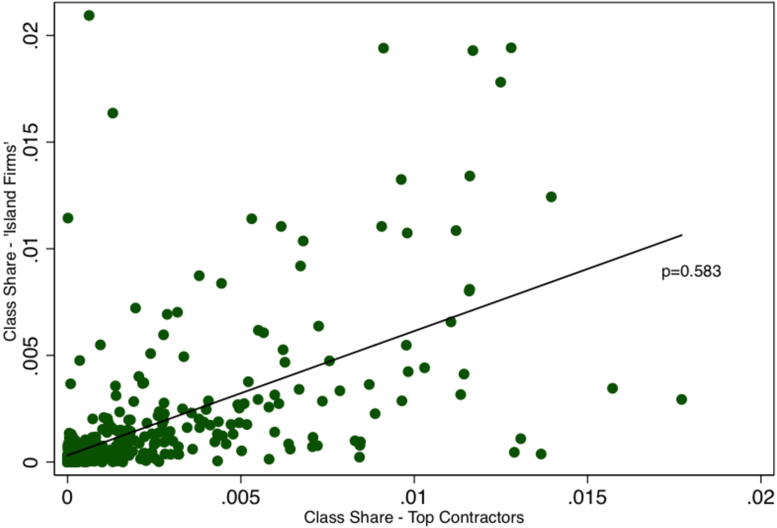


Figure 5b - Technological Distance, Islands versus Top Contractors.



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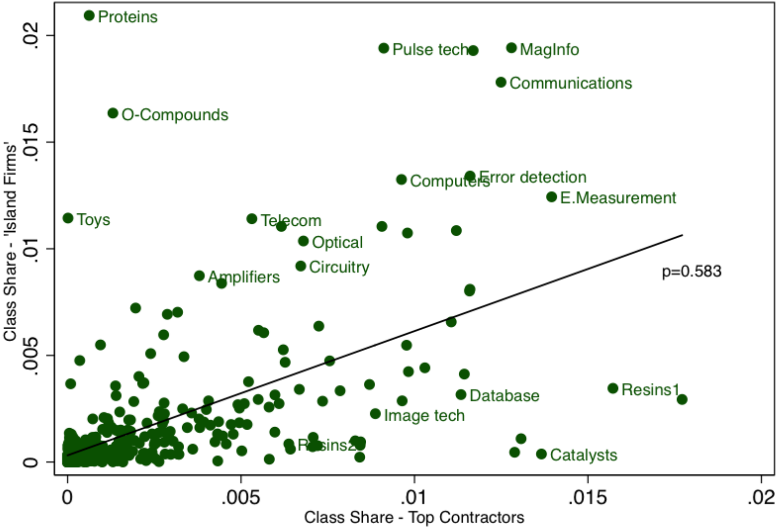

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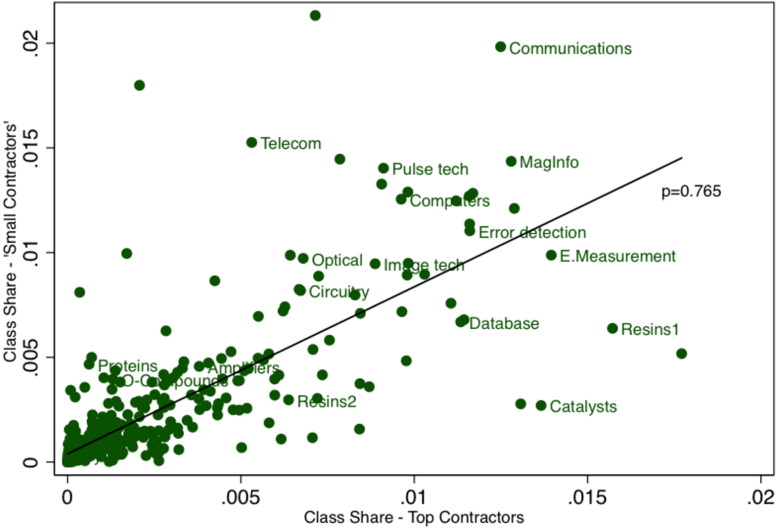

Conclusion / Extensions.

- More on market size variation + firm-to-firm knowledge spillover controls.
- Spending shocks based on 'winning and losing supply chains' through big contract awards.
- More complex empirical information on firm-to-firm network structure.

Table 6: Cascade Effects - Market Size vs Technological Spillovers

	ln(Sales)		
	(1)	(2)	(3)
Cascade Shock$_{t-1}$	0.260***		
	(0.059)		
Cascade Market Size Shock$_{t-1}$		0.223***	0.218***
		(0.062)	(0.062)
ln(Tech Spill)$_{t-1}$			1.291***
			(0.466)
Number of Firms	817	817	817
Number of Observations	9,895	9,895	9,895

Analytical Framework (1)

- 3 agents in the simplest supply chain:
  - Final consumer: downward sloping demand curve
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- Key result: Cascading Innovation
  - Increasing the extent of the final demand good's market $\rightarrow$ worthwile to engage in cost-reducing innovation *at all levels of the supply chain*

- These are simple market size mechanics:
  - *Downstream:* Downstream producer faces (the traditional) direct market size effect + cost reduction effect on its intermediate input (given upstream innovation)
  - *Upstream:* Upstream producer faces a (derived) demand increase: increasing the size of the final demand goods' market leads to *recursive* market size effects up the supply chain.
    - This is a novel *pecuniary* spillover channel.

Analytical Framework (1)

- Consider 3 firms:
  - Downstream final demand producer
  - 2 Upstream intermediate input suppliers
- Downstream firm:
  - 1 unit of final demand requires 1 unit of intermediate input price + processing.
  - Total cost of producing 1 unit of final demand: $p(x) + c(k_d)$
  - Cost reducing innovation (k_d) under decreasing returns:

$$c(k_d) > 0, c'(k_d) < 0, c''(k_d) > 0$$

  - Faces downward sloping demand for final good:

$$P(y) = a - y$$

Analytical Framework (2)

- Consider 3 firms:
  - Downstream final demand producer
  - 2 Upstream intermediate input suppliers
- Upstream firms:
  - Symmetric Cournot
  - Total cost of producing 1 unit of intermediate input x: $c(k_u)$
  - Cost reducing innovation (k_u) under decreasing returns

$$c(k_u) > 0, c'(k_u) < 0, c^{''}(k_u) > 0$$

  - Final good firm is sole source of demand.

Analytical Framework (3)

- Solve for profit max. equilibrium in two stages:
  - 1st Stage: Firms decide on levels of R&D spending
  - 2nd Stage: Firms decide on quantities produced conditional on levels of R&D spending
- Want to know:
  - Upstream and Downstream: Profits, Quantities Produced and R&D
  - Following an increase in market size for final good ($a \uparrow$)

Analytical Framework (4)

Results/Comparative Statics

- Proposition: For a large enough, increasing the market size for the downstream final good ($a \uparrow$) leads to:
  - Increasing downstream and upstream profits:

$$\frac{\partial \pi_d}{\partial a} > 0 \& \frac{\partial \pi_u}{\partial a}$$

  - Increasing downstream and upstream quantities:

$$\frac{\partial y}{\partial a} > 0 \& \frac{\partial x}{\partial a} > 0$$

  - Increasing downstream and upstream innovation:

$$\frac{\partial k_d}{\partial a} > 0 \& \frac{\partial k_u}{\partial a} > 0$$

Analytical Framework (5)

Results/Comparative Statics

- These are simple market size mechanics:
  - Increasing the extent of the market $\rightarrow$ worthwile to engage in cost-reducing innovation *at all levels of the supply chain*
    - *Downstream:* Downstream producer faces (the traditional) direct market size effect + cost reduction effect on its intermediate input (given upstream innovation)
    - *Upstream:* Upstream producer faces a (derived) demand increase: increasing the size of the final demand goods' market leads to recursive market size effects up the supply chain.