Opening up Military Innovation: Causal Effects of 'Btoom-Up' Reforms to U.S. Defense Research

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Outline

Top-down vs. Bottom-up

- Design of innovation incentives important
  - ▶ Especially amid slowdown in productivity growth
    Decker et al. 2016, Syverson 2017

- Relatively overlooked but crucial choice dimension in the search for ideas:
  - ▶ Centralized **"top-down"** approach soliciting a particular technology
  - ▶ Open **"bottom-up"** approach in which innovators suggest ideas, reflecting uncertainty about what opportunities exist

- Bottom-up innovation policy may be especially useful if, in a larger and more diverse economy, it has become more difficult for technology-deploying institutions to find innovations
  Jones 1995, Bloom et al. 2020

Problem salient at U.S. Department of Defense (DoD)

- Concern among top policymakers about U.S. defense R&D
  - Innovation procurement narrowly specified
  - Siloed in small group of defense firms
    Cox et al. (2014), Griffin (2019)

- We show (for first time) that indeed U.S. defense sector growing *less* innovative compared to rest of U.S. economy since early 1990s
  - Coincides with extensive M&A activity that consolidated the defense industrial base

- From DoD's perspective, problematic if best technologies no longer marketed to the military

- From social perspective, may be significant productivity growth implications from DoD's attenuated role in funding frontier ideas

The Open Topic Reforms

- As part of effort to address these issues, U.S. Air Force experimented with "Open" topics in SBIR in 2018
  - ▶ Firms propose *any* idea or technology that could be useful to Air Force
  - ▶ Premised on idea that it has become harder for military to find ideas in the economy that are relevant to its changing activities
- Conventional program identifies specific needs for incremental improvement
  - ▶ e.g., higher quality silver paint for airplanes
- Both focus on applied (development) stage of R&D
  - ▶ Firm already has tech, will develop it further, especially for military use
  - ▶ Common goal: Commercialize tech in DoD and private sector
- Difference is which agent identifies the problem (firm or gov't)
  - ▶ Two programs highlight importance of efficient search for new technologies

This Paper

- By using administrative data to compare Open and Conventional – run simultaneously and with same review process – we can make progress toward comparing bottom-up vs. top-down R&D policies

- Research questions:
  1) Did Open attract new entrants to overall market (i.e. young firms) and to defense SBIR market?
  Yes

  2) What is the causal effect of the two programs on innovation and non-SBIR DoD contracting outcomes?
  Positive for Open, null for Conventional

  3) Beyond selection, was the "bottom-up" nature of Open a critical part to its success?
  Yes

Defense R&D & SBIR Useful Setting

- Dual-use aspect of frontier defense technology $\Rightarrow$ large spillovers to private sector
  - ▶ U.S. DoD historically key funder and early customer for transformational tech (GPS, radio, crypto, nuclear power, jet engines...)
    Mowery and Rosenberg (1991), Mazzucato and Semieniuk (2017)

- DoD one of the largest single investors in R&D in the world, comprises about 60% of U.S. federal R&D
  Congressional Research Service (2018)

- SBIR program among world's largest and most influential gov't small business innovation programs
  - ▶ $3.11 billion across 11 Federal agencies in 2018
    - ★ Of this, DoD accounted for $1.32 billion
    - ★ Air Force had largest single program, $664 million

- Study government as a customer rather than a regulator and financier
  - ▶ Extensive literature on latter two roles
    Jaffe and Palmer (1997), Bloom et al. (2002), Denes et al. (2020)
  - ▶ Former quantitatively important in U.S. and more so elsewhere

Broader Implications

- Whether a bottom-up approach to innovation can be successful is a longstanding economic question
  Azoulay and Li 2020

- Question relevant for diverse public and private institutions
  - E.g. NIH funds both "investigator-initiated competitions" (like Open) and specific "requests for applications" (like Conventional)
    Myers 2020
  - Government agencies around the world use open solicitations (EU, UK, DARPA, DOE)
  - Companies increasingly using bottom-up approaches through customer-driven, outsourced, or open innovation, especially in R&D-intensive industries
   Chesbrough 2003, de Villemeur and Versaevel 2019

Outline

Our Setting: The Small Business Innovation Research Program

- Use administrative data on more than 21,000 applications and evaluations of Air Force SBIR proposals 2003-2019 period
  - ▶ Focus on 2017-19 when Open and Conventional programs run simultaneously
  - ▶ Restrict to Phase 1: Small awards funding proof-of-concept work (firms can later apply for larger Phase 2)
- SBIR program different from overall DoD procurement
  - ▶ Firms must be small to participate so consolidation not a primary concern
  - ▶ Insularity challenge manifests primarily through lock-in, where incumbent contractors who repeatedly apply and win many contracts, apparently relying on SBIR for revenue and failing to produce technology that is useful for military operations
  - ▶ No classified ("secret") SBIR topics or projects

SBIR Process at the Air Force

- 1) Air Force issues a public solicitation for applications
  - ▸ One or more "topics," each of which is a competition

- 2) Multiple government evaluators independently score application on Technology, Team, and Commercialization quality
  - ▸ Three sub-scores are summed

- 3) Winners are those whose overall scores are above a threshold determined by the amount of funding available
  - ▸ Treatment (award) is exogenous to the running variable (score)
  - ▸ Scores and loser identities never public

Selection into New Programs
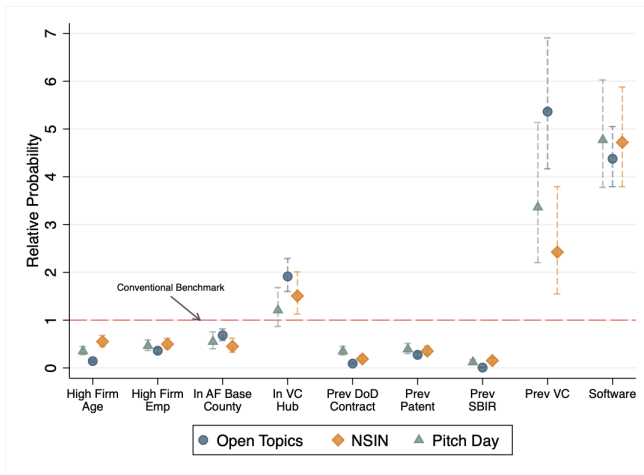
- Open applicants on average half as old and half as big as Conv
- 23% of Open applicants have prev DoD SBIR; 63% of Conv have prev DoD SBIR

▸ Prop Counts ▸ Sum Stats ▸ Geo Dispersion ▸ Tech Kmeans Cluster Dists and Wordclouds

Outline

- Within one program:

$$Y_{it} = \alpha + \alpha_T + \beta \left[1 \mid Rank_{iT} > 0 \right] + \gamma_1 \left[Rank_{iT} \mid Rank_{iT} > 0 \right]$$
$$+ \gamma_2 \left[Rank_{iT} \mid Rank_{iT} < 0 \right] + \delta PSBIR_{iT} + \varepsilon_{iT}$$

- Compare multiple programs:

$$Y_{it} = \alpha + \alpha_T + \beta \left[1 \mid Rank_{iT} > 0 \right] \cdot \text{Program}_T'$$
$$+ \gamma_1 \left[Rank_{iT} \mid Rank_{iT} > 0 \right] \cdot \text{Program}_T' + \gamma_2 \left[Rank_{iT} \mid Rank_{iT} < 0 \right] \cdot \text{Program}_T'$$
$$+ \delta PSBIR_{iT} \cdot \text{Program}_T' + \varepsilon_{iT}.$$

▸ RDD is Sharp ▸ Density Test ▸ Cont of Covs

Outline

Probability of VC within 24 months after award by rank around cutoff

(a) Open

(b) Conventional

Panel A: Any Subsequent Venture Capital Investment

	(1)	(2)	(3)	(4)	(5)	(6)
$\mathbb{1}$(Award)	0.054**	-0.005	0.010	-0.005	0.010	0.005
	(0.025)	(0.019)	(0.010)	(0.019)	(0.010)	(0.003)
$\mathbb{1}$(Award) $\times$ $\mathbb{1}$(Open Topic)				0.059**	0.045*	0.046*
				(0.027)	(0.023)	(0.025)
Observations	1385	2608	7384	3993	8769	21432
Program	Open	Conv.	Conv.	Both	Both	Both
Proposal	First	First	First	First	First	All
Time Period	2017-19	2017-19	2003-19	2017-19	2003-19	2003-19
Outcome Mean	0.079	0.019	0.017	0.040	0.027	0.017

Winning Open increases P(VC) by 5.4pp (68% of the mean)

Panel A: Any Subsequent Venture Capital Investment

	(1)	(2)	(3)	(4)	(5)	(6)
$\mathbb{1}$(Award)	0.054**	-0.005	0.010	-0.005	0.010	0.005
	(0.025)	(0.019)	(0.010)	(0.019)	(0.010)	(0.003)
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No effect of winning
Conventional in 2017-19

Even over the full sample
period from 2003-19

Panel A: Any Subsequent Venture Capital Investment

	(1)	(2)	(3)	(4)	(5)	(6)
$\mathbb{1}$(Award)	0.054**	-0.005	0.010	-0.005	0.010	0.005
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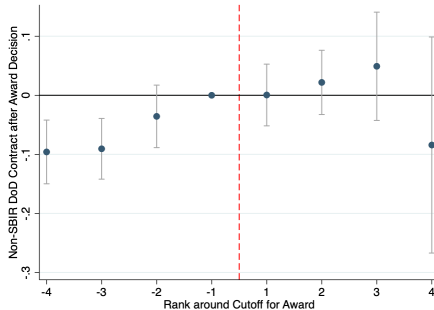The winning effect of Open is significantly different than Conventional

Holds true even when we include all proposals

Effect on probability of non-SBIR DoD contracts within 24 months
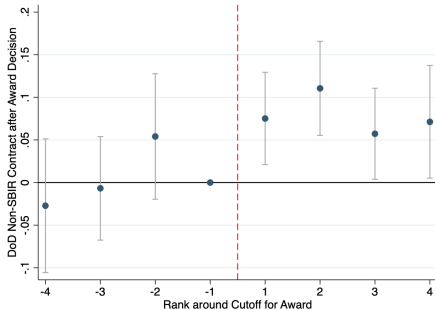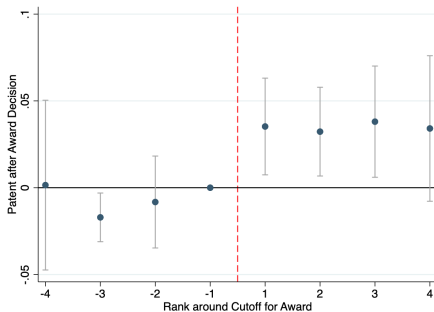
(a) Open

(b) Conventional

- Regressions find strong positive effect in Open, none in Conventional
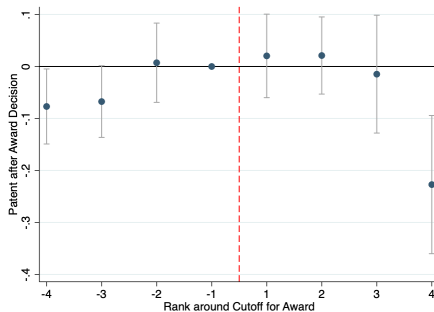 ▸ Regressions

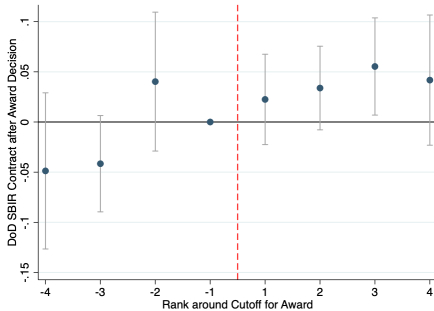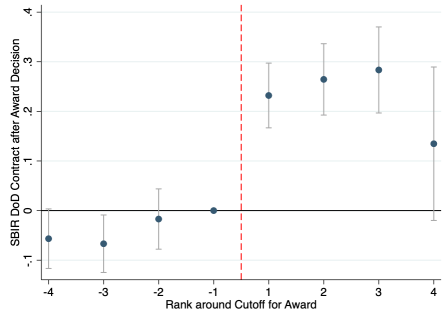# Effect on probability of patents within 24 months

(a) Open

(b) Conventional

▸ Regressions

Effect on probability of Air Force SBIR contracts

(a) Open

(b) Conventional

Regressions

Interpretation

- Winning Open competition has significant positive causal effects on future innovation (VC, patenting) and translating this R&D into military technology (non-SBIR DoD contracts)

- Winning Conventional competition has no causal effects on these outcomes, instead creates lock-in (future SBIR contracts)

- Open topics may work because firms bring existing idea oriented primarily to civilian market to an AF customer who did not know they needed the innovative product
  - May have such a large effect on VC because Open contracts represent entry point to much larger DoD contracts

Outline

Mechanism

- Is the success of Open due to the bottom-up "openness"?
  - ▶ Or composition of applicants (i.e. selection)? Or some other feature?

- Selection: Open attracted firms with larger treatment effects
  - ▶ Entrant/Tech Type status don't explain results in heterogeneity analysis ▸ Go
  - ▶ We look at other program reforms (NSIN, Pitch Day) that also attracted new entrants, but are not bottom-up: No effects ▸ Go

- Decentralized: Bottom-up nature of Open competitions meant that firms came up with more successful ideas
  - ▶ Consistent with this, we find that within Conventional, less specific topics had more positive effects on patent quantity and quality ▸ Go

Outline

Cost-Benefit Analysis

- Consider the Air Force's objective function:

$$V = \mu^M \underbrace{M(D, u^M)}_{\text{Military Benefits}} + \mu^N \underbrace{N(VC, u^N)}_{\text{Non-Military Benefits}} - C$$

  - where μ^M is the welfare weight of military benefits and μ^N is the welfare weight of non-military benefits
  - D is the dollar value of non-SBIR contracts and VC is the dollar value of VC funding
  - u^M and u^N are the unobserved military and non-military benefits, respectively
  - C represent the cost of running an SBIR program.

- **Marginal Decision:** For the next competition, what is the net benefit?
  - Assume one winner & 5 losers
  - Use our estimated causal effects, average dollar values for VC and non-SBIR contracts, and USAF estimated costs

Cost-Benefit Results

All $ in thousands

A. Baseline Results

Program: Outcome:	Open VC (1)	Open Non-SBIR (2)	Conv VC (3)	Conv Non-SBIR (4)
1. Treatment Effect	0.054	0.075	-0.005	0.033
2. Average Contract Size	$11,085	$11,800	$11,805	$11,800
3. Implied Benefit	$599	$885	-$55	$389
4. Utility Weight	1	1	1	1
5. Benefit Sum	$1,484		$334	
6. Cost	$379		$333	
7. Net Benefit (Benefit - Cost)	$1,104		$1	
8. Net Benefit Difference (Open - Conv)	$1,103			

- Robust to wide array of sensitivity tests ▸ Go

Outline

Conclusion

- Trade-offs in innovation investment between decentralized (bottom-up) and centralized (top-down) strategies

- Open reforms seem to have benefits for DoD and private sector
  - ▶ Selection: Reduces barriers to entry, minimize lock-in advantages for incumbents, and attracts wider range of new entrants
  - ▶ Openness: Seems to play an additional role

- US military R&D is key exhibit for supporters of mission-driven, innovation-based industrial policy.
  - ▶ Recent trend of faltering innovation in this important sector
  - ▶ We present the first causal evaluation of a defense R&D program

- Relevant beyond defense: E.g. Companies use bottom-up approaches

- Innovation funders could benefit from more bottom-up, decentralized approaches

Consolidation of Prime Defense Contractors
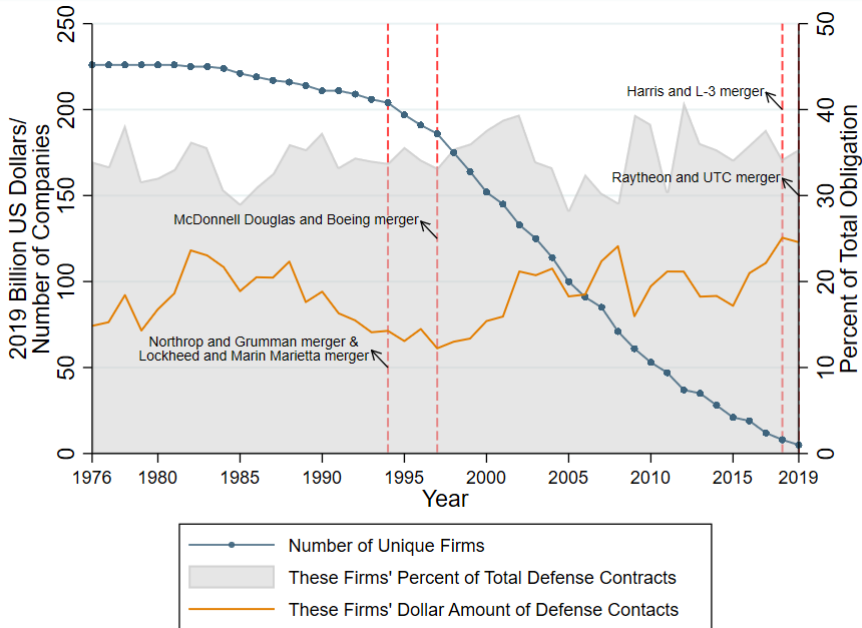
Harris and L-3 merger

Raytheon and UTC merger

McDonnell Douglas and Boeing merger

Northrop and Grumman merger &
Lockheed and Marin Marietta merger

- Number of Unique Firms
- These Firms' Percent of Total Defense Contracts
- These Firms' Dollar Amount of Defense Contacts

Innovation Dynamics of Prime Defense Contractors

(a) Prime Patent Citations
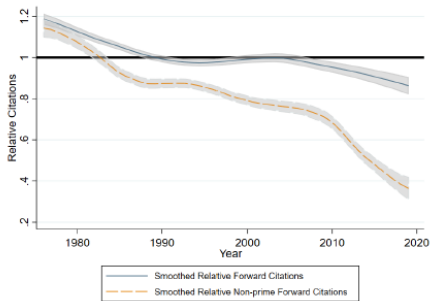
(b) Conventional SBIR Winner Patent Citations
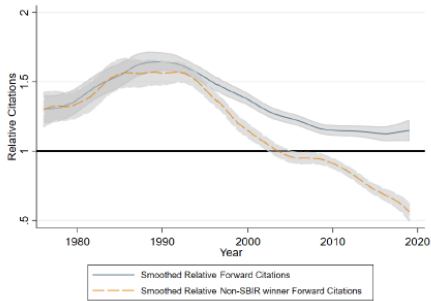
- Dashed line: citations from non-defense contractors offers proxy for knowledge spillovers to broader economy, versus being insular to defense industrial base

Innovation Dynamics of Prime Defense Contractors

(a) Prime Patent Citations
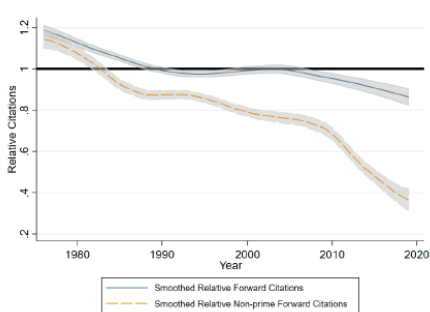
(b) Conventional SBIR Winner Patent Citations
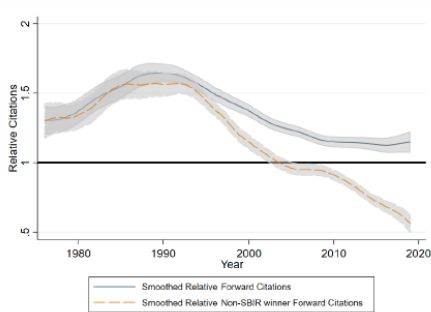
- Relationship is not mechanical from consolidation because we do not count cites from a future acquirer as self-cites
- Prime and target share of patents in a class-year has declined over time, so there are not "fewer outside patents to cite" in a class-year

Historical Dynamics of Prime Defense Contractors

(a) Number of Patents
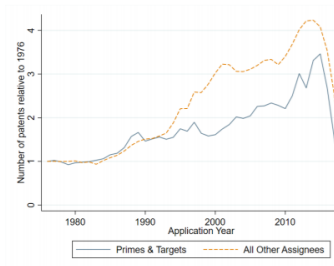
(b) Profit per Dollar R&D
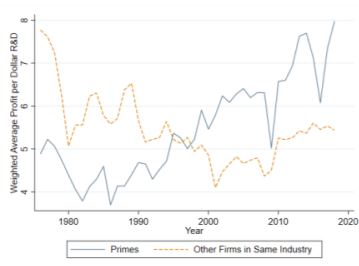
(c) Profits
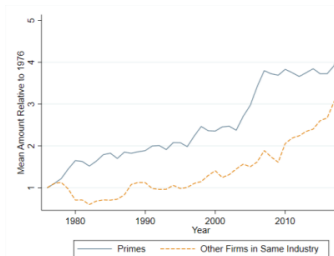
(d) Total Assets, Revenue, and R&D Expenditure
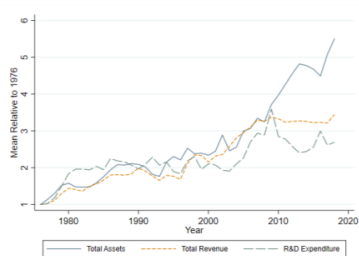
▸ Back

Classifying applications as technologies

- There is no pre-classification into techs/industries
- We use text in proposal abstracts in ML algorithm called k-means clustering
  - ▶ Classify each abstract based on its word "embedding": process converts the text into vectors of numbers
- Each application represented by a vector, elements reflect word embeddings
  - ▶ Then can cluster applications into groups based on the similarity of the vectors (i.e. minimizing the total within-cluster variance using their vector representation)
- We present 5 and 2cluster model
  - ▶ 5 is empirically the optimal number of clusters
  - ▶ 2 clusters yields clear dichotomy between software- and hardware-based technologies

Wordcloud for 2-topic K-means clustering of abstract text

(a) Hardware
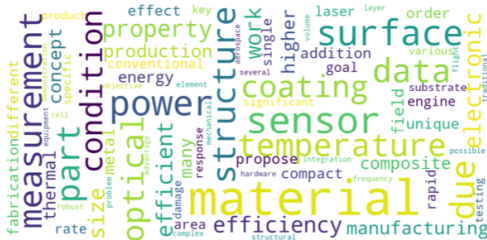
(b) Training/Software

K-means clustering of abstract text by program type and winner status

(a) Model with Two Clusters
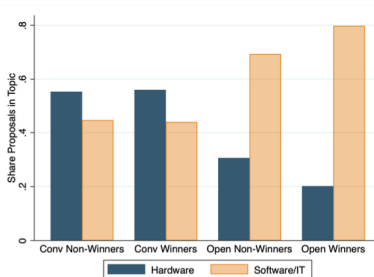
(b) Model with Five Clusters
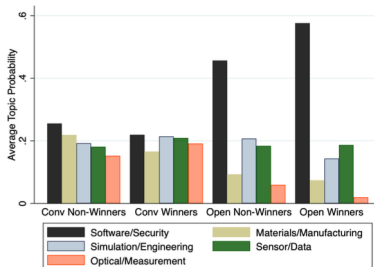
K-means clustering of abstract text by program type and entrant status
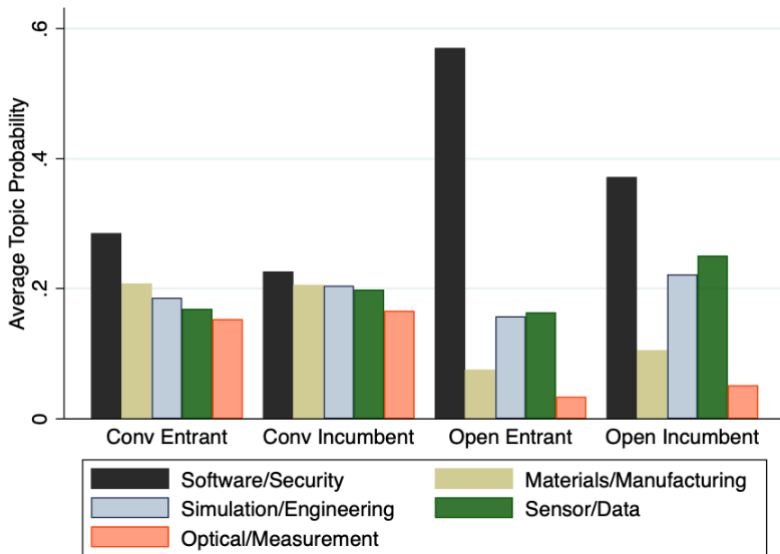
Constructing Non-Specificity Index

- For each Conventional proposal abstract, we do the following:
  - ▶ First, map each word of the abstract into vector space using a pre-trained model
    - ★ Each word is represented by a 300-dimension vector called an "embedding"
    - ★ Each element in an embedding takes a value between -1 and $+1$
  - ▶ Second, take the average across each dimension to produce one vector that represents the average position of the abstract in vector space.
  - ▶ Third, reduce the dimensionality using isometric mapping, following Tenenbaum et al. (2000)

- Each proposal is represented as a 2-dimensional vector

- The nonspecificity index N_t for topic t with P proposals is constructed as the following:

$$N_t = \frac{\sum_i^P ||\vec{x_i} - \vec{\bar{x}}||^2}{P}$$

▶ Back

Geographic Dispersion of Applications (2017-19)

(a) Open Topic Applications and VC Deals
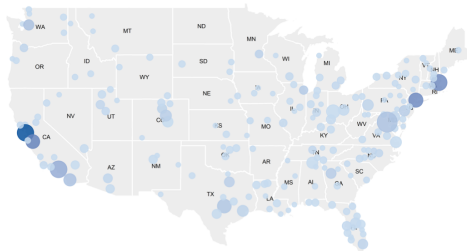
(b) Conventional Topic Applications and VC Deals

Summary Statistics

Panel A: Competition and Company Summary

	Open Topic				Conventional			
	N	Mean	Median	SD	N	Mean	Median	SD
Competition Summary								
Num Proposals per Topic	1,659	379.327	375	156.453	4,995	19.808	15	17.131
Num Winners per Topic	1,659	212.842	297	115.083	4,995	3.090	2	3.606
Topic Non-Specificity	1,648	3.907	4	0.515	4,974	1.000	1	0.540
Award Amount	269	$49,569	$50,000	$14,636	876	$147,235	$152,718	$25,296
Company Characteristics								
Age	1,659	9.794	5	10.981	4,995	18.166	16	13.133
Number of Employees	1,659	26.885	8	60.687	4,995	60.774	20	90.802
1(in VC Hub)	1,659	0.197		0.397	4,995	0.148		0.355
1(in County with AF Base)	1,659	0.192		0.394	4,995	0.275		0.446
1(Minority Owned)	1,659	0.121		0.326	4,993	0.127		0.333
1(Woman owned)	1,659	0.111		0.314	4,993	0.155		0.362
1(Proposal is Hardware)	1,659	0.240		0.427	4,995	0.514		0.500

Panel B: Pre-Award Outcome Summary

	Open Topic				Conventional			
	N	Mean	Median	SD	N	Mean	Median	SD
1(VC)	1,659	0.114		0.318	4,995	0.060		0.238
Avg VC Amt (Mill)	154	$6.859	$1.925	$14.683	204	$3.643	$0.700	$6.633
1(DoD Non-SBIR Contract)	1,659	0.253		0.435	4,995	0.601		0.490
# DoD Non-SBIR Contracts	420	12.310	4	33.286	3,000	20.174	9	29.737
Avg DoD Non-SBIR Contract Amt (Mill)	420	$1.631	$0.697	$2.772	3,000	$1.757	$0.868	$4.189
1(Patent)	1,659	0.250		0.433	4,995	0.473		0.499
# Patents	415	12.313	3	39.420	2,364	26.678	10	45.638
# Patent Application if Any	515	10.996	3	36.026	2,554	25.691	9	45.461
1(AF SBIR Contract)	1,659	0.189		0.391	4,995	0.593		0.491
# AF SBIR Contracts	313	21.856	8	40.649	2,960	50.405	18	76.366
1(Never Awarded SBIR)	1,659	0.691		0.462	4,995	0.283		0.451

▸ Back

Proposal Counts

Panel A: Open & Conventional (2017-19)

	Both	Open Topic	Conventional
Number of Topics:			
Phase I	512	6	506
Phase II	180	5	175
Number of Proposals:			
Phase I	7229	1656	5573
Phase II	865	444	421
Number of Firms:			
Applied to Type	3170	1408	2409
Exclusively Applied to Type	647	761	1762

Panel B: Full Sample (2003-2019)

	Both	Open Topic	Conventional
Number of Topics:			
Phase I	1796	6	1790
Phase II	661	5	656
Number of Proposals:			
Phase I	19446	1656	17790
Phase II	1684	444	1240
Number of Firms:			
Applied to Type	6485	1419	5724
Exclusively Applied to Type	658	761	5066

Panel C: NSIN and Pitch Day

	Both	NSIN	Pitch Day
Number of Topics:			
Phase I	11	8	3
Phase II	2	1	1
Number of Proposals:			
Phase I	747	423	324
Phase II	28	18	10
Number of Firms:			
Applied to Type	606	361	286
Exclusively Applied to Type	41	320	245

▸ Back

(a) Applications

(b) Awards
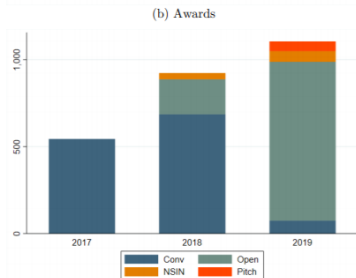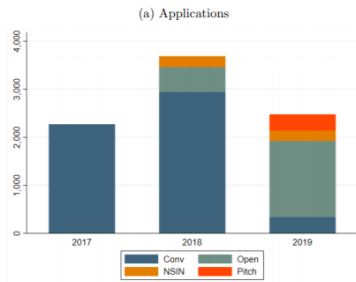
Histograms of Award Amounts by Topic Type and Phase
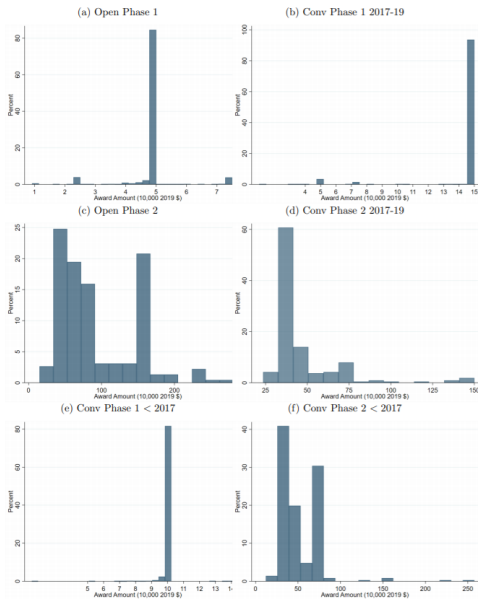
Concentration of Federal Contracts

(a) Concentration of Department of Defense SBIR and Non-SBIR Contracts

(b) Share of Firms without Recent Repeat Contracts in Two SBIR Programs
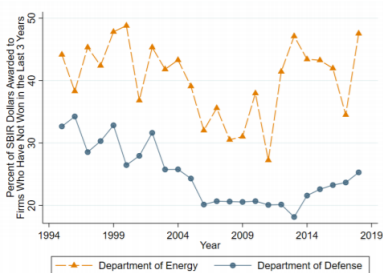
Robustness Test (Part 1)

Panel A: Controls

Dep Var:	Any VC		Any Patents		Any DoD Contracts		Any SBIR	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$\mathbb{1}$(Award)	0.051**	-0.006	0.049***	0.064	0.057*	0.028	0.040	0.189***
	(0.025)	(0.017)	(0.017)	(0.042)	(0.034)	(0.049)	(0.028)	(0.043)
Observations	1385	2608	1385	2608	1385	2608	1385	2608
Program	Open	Conv	Open	Conv	Open	Conv	Open	Conv
Outcome Mean	0.079	0.019	0.027	0.146	0.148	0.324	0.105	0.299

Panel B: No Controls

Dep Var:	Any VC		Any Patents		Any DoD Contracts		Any SBIR	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$\mathbb{1}$(Award)	0.060**	-0.005	0.049***	0.081*	0.045	0.040	0.021	0.204***
	(0.025)	(0.018)	(0.016)	(0.045)	(0.037)	(0.054)	(0.029)	(0.050)
Observations	1385	2608	1385	2608	1385	2608	1385	2608
Program	Open	Conv	Open	Conv	Open	Conv	Open	Conv
Outcome Mean	0.079	0.019	0.027	0.146	0.148	0.324	0.105	0.299

Panel C: Narrow Bandwidth

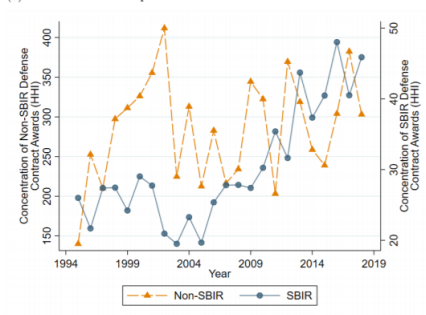| Dep Var:	Any VC		Any Patents		Any DoD Contracts		Any SBIR	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$\mathbb{1}$(Award)	0.062***	0.006	0.037***	0.015	0.072***	0.050	0.022	0.028
	(0.020)	(0.011)	(0.013)	(0.031)	(0.027)	(0.034)	(0.021)	(0.031)
Observations	671	902	671	902	671	902	671	902
Program	Open	Conv	Open	Conv	Open	Conv	Open	Conv
Outcome Mean	0.059	0.018	0.021	0.216	0.153	0.434	0.089	0.550

Panel D: All Proposals

Dep Var:	Any VC		Any Patents		Any DoD Contracts		Any SBIR	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$\mathbb{1}$(Award)	0.051**	-0.000	0.047***	0.065**	0.088***	0.006	0.009	0.097***
	(0.024)	(0.012)	(0.015)	(0.031)	(0.033)	(0.034)	(0.029)	(0.035)
Observations	1659	4995	1659	4995	1659	4995	1659	4995
Program	Open	Conv	Open	Conv	Open	Conv	Open	Conv
Outcome Mean	0.079	0.014	0.028	0.142	0.160	0.467	0.113	0.442

Robustness Test (Part 2)

Panel E: Ever-After Outcomes

Dep Var:	Any VC		Any Patents		Any DoD Contracts		Any SBIR	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$\mathbb{1}$(Award)	0.054**	-0.012	0.051***	0.064	0.075**	0.027	0.040	0.172***
	(0.025)	(0.022)	(0.017)	(0.044)	(0.035)	(0.047)	(0.028)	(0.045)
Observations	1385	2608	1385	2608	1385	2608	1385	2608
Program	Open	Conv	Open	Conv	Open	Conv	Open	Conv
Outcome Mean	0.079	0.025	0.027	0.151	0.148	0.362	0.105	0.312

Panel F: Conventional 2003-2017

Dep Var:	Any VC	Any Patents	Any DoD Contracts	Any SBIR
	(1)	(2)	(3)	(4)
$\mathbb{1}$(Award)	0.011	-0.018	0.022	0.332***
	(0.008)	(0.023)	(0.025)	(0.024)
Observations	6628	6628	6628	6628
Outcome Mean	0.016	0.171	0.239	0.206

▸ Back

Effect of Winning Phase 1 Interacted with Phase 2 Match

Dependent Variable:	VC If No Prvt Match	VC If Prvt Match	Any VC		
Sample:			Match Offered	No Match Offered	
	(1)	(2)	(3)	(4)	(5)
$\mathbb{1}$(Award)	0.040*	0.015	-0.047	0.074	0.026
	(0.025)	(0.013)	(0.042)	(0.062)	(0.049)
$\mathbb{1}$(Award × Match Offered in Topic)					0.030
					(0.042)
Observations	1385	1385	1004	381	1385
Outcome Mean	0.068	0.027	0.083	0.071	0.079

Prevalence of Crossover Sub-scores

(a) Tech Score
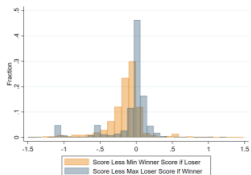
(b) Team Score
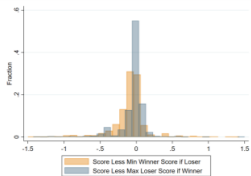
(c) Commercialization Score
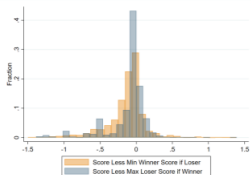
Total score does not predict outcomes

Panel A: Total Score

Dep Var:	Any VC		Any Patents		Any DoD Contracts		Any SBIR	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Total Score	0.009	0.005	-0.016	0.014	0.007	0.041	0.084***	-0.006
	(0.016)	(0.011)	(0.011)	(0.027)	(0.026)	(0.040)	(0.031)	(0.032)
Observations	1385	2608	1385	2608	1385	2608	1385	2608
Program	Open	Conv	Open	Conv	Open	Conv	Open	Conv
Outcome Mean	0.079	0.019	0.027	0.146	0.148	0.324	0.105	0.299

Sub-scores can predict relevant outcomes

Panel B: Commercial Score

Dep Var:	Any VC		Any Patents		Any DoD Contracts		Any SBIR	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Commercial Score	0.081***	0.029	0.001	0.011	0.047**	0.095*	0.044*	0.046
	(0.020)	(0.030)	(0.011)	(0.039)	(0.024)	(0.056)	(0.023)	(0.044)
Observations	1385	2608	1385	2608	1385	2608	1385	2608
Program	Open	Conv	Open	Conv	Open	Conv	Open	Conv
Outcome Mean	0.079	0.019	0.027	0.146	0.148	0.324	0.105	0.299

Panel C: Team Score

Dep Var:	Any VC		Any Patents		Any DoD Contracts		Any SBIR	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Team Score	-0.115***	0.020	-0.033**	0.028	0.008	-0.021	-0.013	-0.037
	(0.023)	(0.046)	(0.014)	(0.043)	(0.029)	(0.062)	(0.030)	(0.052)
Observations	1385	2608	1385	2608	1385	2608	1385	2608
Program	Open	Conv	Open	Conv	Open	Conv	Open	Conv
Outcome Mean	0.079	0.019	0.027	0.146	0.148	0.324	0.105	0.299

Panel D: Technical Score

Dep Var:	Any VC		Any Patents		Any DoD Contracts		Any SBIR	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Technical Score	0.004	-0.048	0.009	0.002	-0.064**	0.009	0.059**	-0.053
	(0.023)	(0.059)	(0.012)	(0.042)	(0.031)	(0.064)	(0.027)	(0.054)
Observations	1385	2608	1385	2608	1385	2608	1385	2608
Program	Open	Conv	Open	Conv	Open	Conv	Open	Conv
Outcome Mean	0.079	0.019	0.027	0.146	0.148	0.324	0.105	0.299

Phase 2 Competition Summary Statistics

Panel A: Competition and Company Summary

	Open Topic				Conventional			
	N	Mean	Median	SD	N	Mean	Median	SD
Competition Summary								
Num Proposals per Topic	647	137.393	163	57.690	459	8.272	2	12.621
Num Winners per Topic	647	77.811	87	40.737	459	1.793	1	1.955
Topic Non-Specificity	627	2.885	3	0.162	441	0.829	0	1.084
Award Amount	62	$832,463	$762,881	$470,903	74	$813,940	$782,165	$183,199
Company Characteristics								
Age	647	8.622	5	9.821	459	22.986	24	13.509
Number of Employees	645	30.484	10	72.174	459	76.490	35	95.453
1(in VC Hub)	647	0.162		0.369	459	0.155		0.362
1(in County with AF Base)	647	0.088		0.284	459	0.283		0.451
1(Proposal is Hardware)	647	0.133		0.340	459	0.429		0.496

Panel B: Pre-Award Outcome Summary

	Open Topic				Conventional			
	N	Mean	Median	SD	N	Mean	Median	SD
1(VC)	647	0.121		0.326	459	0.076		0.266
Avg VC Amt (Mill)	63	$6.080	$2.800	$8.917	25	$3.940	$0.150	$6.930
1(DoD Non-SBIR Contract)	647	0.195		0.396	459	0.706		0.456
# DoD Non-SBIR Contracts	126	10.063	4	14.773	324	27.219	12.5	32.229
Avg DoD Non-SBIR Contract Amt (Mill)	126	$1.553	$0.805	$2.502	324	$1.805	$0.927	$2.572
1(Patent)	647	0.260		0.439	459	0.580		0.494
# Patents	168	12.065	3	42.972	266	24.850	10	34.960
# Patent Application if Any	214	10.664	3	38.826	282	24.316	10	34.797
1(AF SBIR Contract)	647	0.189		0.391	459	0.728		0.446
# AF SBIR Contracts	122	13.180	2	23.481	334	62.141	20	86.903
1(Never Awarded SBIR)	647	0.742		0.438	459	0.214		0.410

Outcome Variable Summary for Special Programs

Panel A: Competition and Company Summary

	Conventional, 2003-19				NSIN & Pitch Day			
	N	Mean	Median	SD	N	Mean	Median	SD
Competition Summary								
Num Proposals per Topic	19,773	18.620	16	12.568	747	78.898	73	27.573
Num Winners per Topic	19,773	3.167	2	3.959	747	14.100	16	5.183
Topic Non-Specificity	19,717	0.977	1	0.582	738	2.257	2	0.985
Award Amount	3,561	$137,120	$130,924	$27,111	83	$119,444	$146,451	$41,841
Company Characteristics								
Age	19,773	15.572	13	12.010	747	12.746	7	12.751
Number of Employees	19,773	48.322	16	76.341	747	34.000	8	76.972
1(in VC Hub)	19,773	0.173		0.379	747	0.190		0.393
1(in County with AF Base)	19,773	0.280		0.449	747	0.170		0.376
1(Minority Owned)	19,773	0.032		0.176	747	0.158		0.365
1(Woman owned)	19,773	0.045		0.207	747	0.123		0.329
1(Proposal is Hardware)	19,773	0.536		0.499	747	0.169		0.375

Panel B: Pre-Award Outcome Summary

	Conventional, 2003-19				NSIN & Pitch Day			
	N	Mean	Median	SD	N	Mean	Median	SD
1(VC)	19,773	0.060		0.237	747	0.072		0.259
Avg VC Amt (Mill)	832	$ 5.825	$1.810	$8.318	40	$6.003	$1.400	$9.892
1(DoD Non-SBIR Contract)	19,773	0.369		0.483	747	0.301		0.459
# DoD Non-SBIR Contracts	7,301	12.837	4	22.681	225	18.338	5	33.293
Avg DoD Non-SBIR Contract Amt (Mill)	7,301	$2.254	$0.720	$6.985	225	$2.049	$ 1.005	$3.213
1(Patent)	19,773	0.440		0.496	747	0.261		0.439
# Patents	8,705	19.434	6	35.112	195	13.200	5	26.916
# Patent Application if Any	8,925	19.275	6	35.230	238	12.105	4	26.668
1(AF SBIR Contract)	19,773	0.514		0.500	747	0.213		0.410
# AF SBIR Contracts	10,173	34.193	12	57.090	159	38.535	10	65.716
1(Never Awarded SBIR)	19,773	0.367		0.482	747	0.660		0.474

Panel B: Any Subsequent High Citation and Generality Patent

Dep Var:	High Citation		High Generality	
	(1)	(2)	(3)	(4)
$\mathbb{1}$(Award)	-0.002	-0.036*	0.015	-0.052***
	(0.003)	(0.019)	(0.018)	(0.019)
Observations	2608	7384	2608	7384
Program	Conv.	Conv.	Conv.	Conv.
Proposal	First	First	First	First
Time Period	2017-19	2003-19	2017-19	2003-19
Outcome Mean	0.001	0.076	0.010	0.085

Panel A: Any Subsequent High Originality Patent

	(1)	(2)	(3)	(4)	(5)	(6)
$\mathbb{1}$(Award)	0.038***	0.020	-0.027	0.020	-0.027	-0.017
	(0.015)	(0.042)	(0.021)	(0.041)	(0.021)	(0.012)
$\mathbb{1}$(Award) × $\mathbb{1}$(Open Topic)				0.018	0.066**	0.054***
				(0.045)	(0.028)	(0.020)
Observations	1385	2608	7384	3993	8769	21432
Program	Open	Conv.	Conv.	Both	Both	Both
Proposal	First	First	First	First	First	All
Time Period	2017-19	2017-19	2003-19	2017-19	2003-19	2003-19
Outcome Mean	0.018	0.094	0.103	0.068	0.090	0.165

Phase 2 VC and Government Matching Summary Statistics

	N	Mean	Median	SD
Share Government Match	647	0.131		0.338
Share Private Match	647	0.145		0.353
Confirmed Govt Match Amt	79	$769,446	$600,000	$810,078
Confirmed Private Match Amt	23	$1,273,499	$1,500,000	$468,870
Share Applied Government Match	647	0.182		0.386
Share Applied Private Match	647	0.206		0.404
Applied Govt Match Amt	118	$680,240	$529,619	$538,458
Applied Private Match Amt	133	$1,355,232	$1,500,000	$940,224

Within-Firm Effect of an Award in Open relative to Conventional Conditional on Applying to Both

Dep Var:	Any VC	Any DoD non-SBIR	Any Patents	Any DoD SBIR
	(1)	(2)	(3)	(4)
$\mathbb{1}$(Award) $\times$ $\mathbb{1}$(Open Topic)	-0.003	-0.013	0.003	-0.104
	(0.003)	(0.043)	(0.036)	(0.084)
$\mathbb{1}$(Award)	-0.001	-0.079***	-0.037*	-0.093*
	(0.001)	(0.028)	(0.020)	(0.048)
$\mathbb{1}$(Open Topic)	-0.001	-0.082**	-0.075***	-0.130*
	(0.001)	(0.037)	(0.026)	(0.073)
Observations	1259	1259	1259	1259
Outcome Mean	0.056	0.074	0.072	0.365

Effect of Phase 2 Award and Award Amount on VC and DoD non-SBIR Contracts

Panel A: Any Subsequent VC and Non-SBIR DoD Contracts

Dep Var:	Any VC		Any DoD Non-SBIR	
	(1)	(2)	(3)	(4)
$\mathbb{1}$(Award)	-0.058	-0.015	-0.024	-0.004
	(0.063)	(0.017)	(0.141)	(0.078)
Observations	457	1703	457	1703
Program	Conv	Conv	Conv	Conv
Time Period	2017-19	2003-19	2017-19	2003-19
Outcome Mean	0.013	0.009	0.562	0.524

Panel B: Any Subsequent Patenting and SBIR Contracts

Dep Var:	Any Patents		Any SBIR	
	(1)	(2)	(3)	(4)
$\mathbb{1}$(Award)	-0.072	-0.044	0.050	-0.082
	(0.112)	(0.077)	(0.140)	(0.080)
Observations	457	1703	457	1703
Program	Conv	Conv	Conv	Conv
Time Period	2017-19	2003-19	2017-19	2003-19
Outcome Mean	0.100	0.265	0.420	0.579

(a) Firm Age at Application
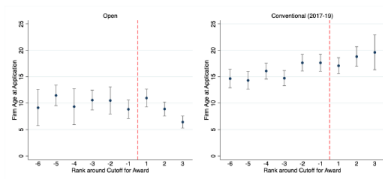
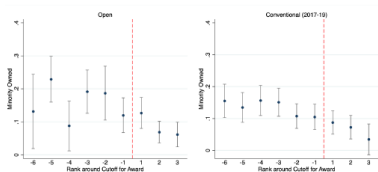(b) Firm Employment at Application
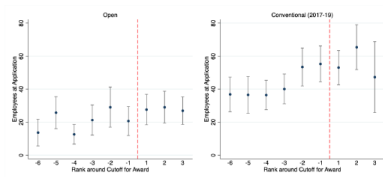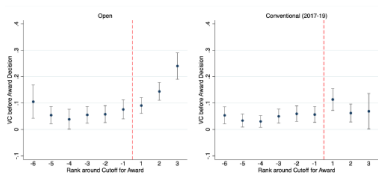
(c) Software vs. Hardware Technology
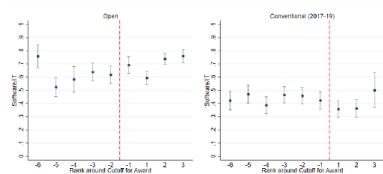
▸ Back

Continuity of Baseline Covariates around Cutoff for Phase 1 Award (Part 2)
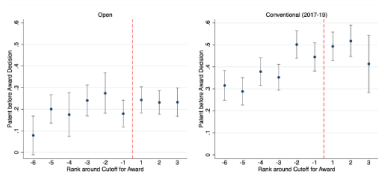

(a) Probability Firm Minority-Owned at Application

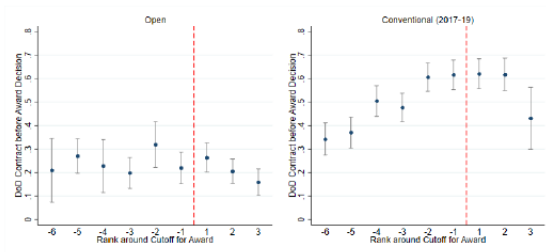(b) Probability of Venture Capital Before Award Decision

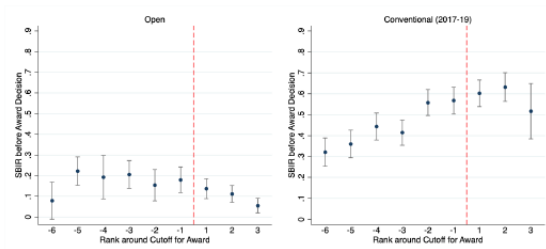(c) Probability of Patent Before Award Decision

Continuity of Baseline Covariates around Cutoff for Phase 1 Award (Part 3)

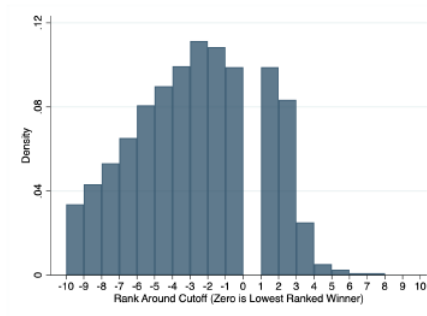(a) Probability of DoD Non-SBIR Contract Before Award Decision

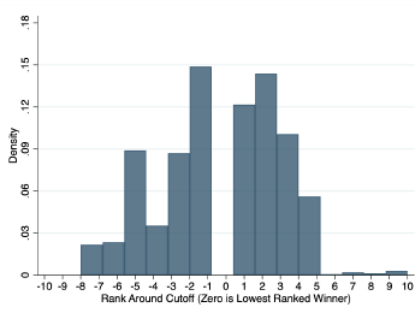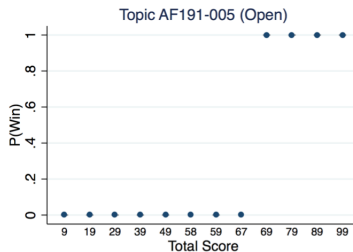(b) Probability of SBIR Before Award Decision

(a) Conventional (2017-19)

(b) Open

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Raw Scores and Award Probability in Four Representative Topics
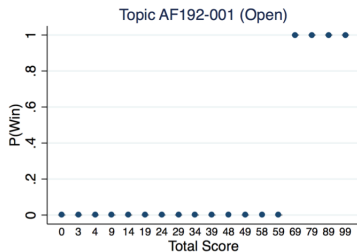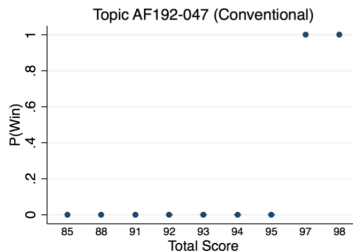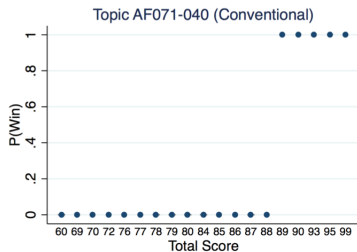
Effect on Any Subsequent Patents

Panel A: Any Subsequent Patents

	(1)	(2)	(3)	(4)	(5)	(6)
$\mathbb{1}$(Award)	0.051***	0.077	-0.022	0.077	-0.022	-0.022*
	(0.017)	(0.051)	(0.025)	(0.050)	(0.025)	(0.013)
$\mathbb{1}$(Award) $\times$ $\mathbb{1}$(Open Topic)				-0.026	0.073*	0.069**
				(0.057)	(0.037)	(0.030)
Observations	1385	2608	7384	3993	8769	21432
Program	Open	Conv.	Conv.	Both	Both	Both
Proposal	First	First	First	First	First	All
Time Period	2017-19	2017-19	2003-19	2017-19	2003-19	2003-19
Outcome Mean	0.027	0.146	0.158	0.105	0.137	0.235

- Winning Open increases prob of subsequent patents by 5.1pp, which is 180% of mean

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Panel B: Any Subsequent SBIR Contracts

	(1)	(2)	(3)	(4)	(5)	(6)
$\mathbb{1}$(Award)	0.040	0.172***	0.288***	0.172***	0.288***	0.123***
	(0.028)	(0.048)	(0.028)	(0.047)	(0.027)	(0.011)
$\mathbb{1}$(Award) × $\mathbb{1}$(Open Topic)				-0.133	-0.248***	-0.114**
				(0.082)	(0.076)	(0.056)
Observations	1385	2608	7384	3993	8769	21432
Program	Open	Conv.	Conv.	Both	Both	Both
Proposal	First	First	First	First	First	All
Time Period	2017-19	2017-19	2003-19	2017-19	2003-19	2003-19
Outcome Mean	0.105	0.312	0.229	0.240	0.210	0.462

- Winning Open has no effect on prob of subsequent DoD SBIR contract, winning Conv increases it dramatically
- Conv shown above is all years, where effect is 29 pp or 120% of the mean

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Heterogeneous effects on VC by entrant status

	(1)	(2)	(3)	(4)	(5)	(6)
$\mathbb{1}$(Award)	0.063**	0.083***	0.043*	0.000	-0.008	0.009
	(0.026)	(0.028)	(0.026)	(0.026)	(0.024)	(0.021)
$\mathbb{1}$(Award) $\times$ $\mathbb{1}$(Prev. SBIR)	-0.072***			-0.008		
	(0.027)			(0.018)		
$\mathbb{1}$(Award) $\times$ $\mathbb{1}$(High Age)		-0.098***			0.004	
		(0.026)			(0.017)	
$\mathbb{1}$(Award) $\times$ $\mathbb{1}$(Hardware)			0.058			-0.022
			(0.037)			(0.015)
Observations	1385	1385	1385	2608	2608	2608
Program	Open	Open	Open	Conv.	Conv.	Conv.
Time Period	2017-19	2017-19	2017-19	2017-19	2017-19	2017-19
Outcome Mean	0.079	0.079	0.079	0.019	0.019	0.019

Incumbents experience
null effect (-0.009 pp)

- VC is only outcome with meaningful interactions, suggests there is something beyond selection

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Other program reforms (NSIN, Pitch Day) Attracted Similar Firms to Open
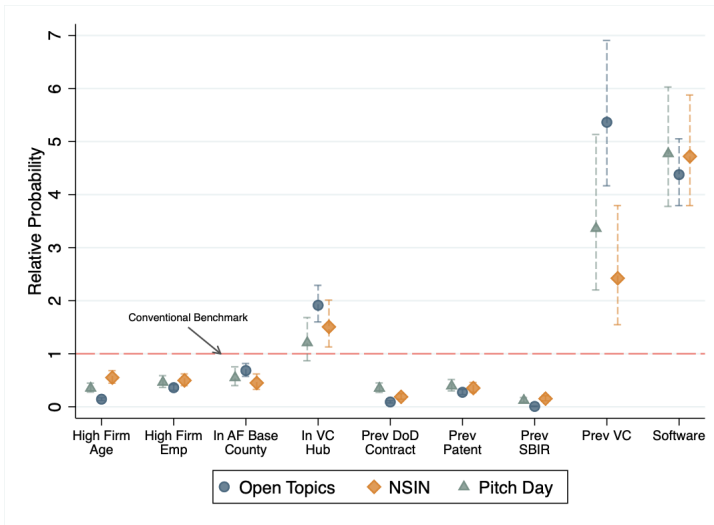
Effect of Open, Conventional, and Other Reform Programs Relative to One Another

Sample:	Open, Conv & NSIN	Open, Conv & Pitch Day	All	NSIN Topics	Pitch Day Topics
	(1)	(2)	(3)	(4)	(5)
$\mathbb{1}(\text{Award}) \times \mathbb{1}(\text{Open Topics})$	0.059**	0.059**	0.059**		
	(0.027)	(0.027)	(0.027)		
$\mathbb{1}(\text{Award}) \times \mathbb{1}(\text{NSIN})$	-0.014		-0.014		
	(0.066)		(0.066)		
$\mathbb{1}(\text{Award}) \times \mathbb{1}(\text{Pitch Day})$		-0.106	-0.106		
		(0.060)	(0.060)		
$\mathbb{1}(\text{Award})$	-0.005	-0.005	-0.005	-0.019	-0.111
	(0.019)	(0.019)	(0.018)	(0.063)	(0.067)
Observations	4416	4317	4740	423	324
Outcome Mean	0.043	0.042	0.044	0.071	0.062

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Cost-Benefit Sensitivity Tests

	Net Benefit Difference (1)	Open Net Benefit (2)	Conv Net Benefit (3)
1. Baseline	$1,103	$1,104	$1
2. Pre-award Average Contract Sizes	$816	$797	-$19
3. Zero Weight on Non-Military	$449	$506	$56
4. Zero Coefficient on VC for Conv	$1,048	$1,104	$56
5. Conv Coefficients from 2003-19	$1,268	$1,104	-$164
6. Separate Contract Size Averages for Open and Conv	$416	$486	$69

- While exact net benefits depend on assumptions, analysis indicates that Planner's marginal decision rule would be to run an Open competition rather than a Conventional one

- Note: This does not mean there is no role for Conventional, because there might be other benefits we are not measuring

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Effect on Any Subsequent Non-SBIR DoD Contracts

Panel B: Any Subsequent Non-SBIR DoD Contracts

	(1)	(2)	(3)	(4)	(5)	(6)
𝟙(Award)	0.075**	0.033	0.015	0.033	0.015	-0.022
	(0.035)	(0.052)	(0.031)	(0.051)	(0.031)	(0.013)
𝟙(Award) × 𝟙(Open Topic)				0.042	0.060	0.109***
				(0.067)	(0.055)	(0.036)
Observations	1385	2608	7384	3993	8769	21432
Program	Open	Conv.	Conv.	Both	Both	Both
Proposal	First	First	First	First	First	All
Time Period	2017-19	2017-19	2003-19	2017-19	2003-19	2003-19
Outcome Mean	0.148	0.324	0.230	0.263	0.217	0.421

- Winning Open increases prob of subsequent non-SBIR DoD contract by 7.5 pp, which is 51% of mean.
- Cannot reject that the effects of winning are the same in Open and Conventional for first proposals, but we can for all proposals.

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Testing Non-specificity

- Score Conventional topics since 2003 on "non-specificity"

- Use NLP "text to data" algorithm to classify applications via words in proposal's abstract
  - e.g. "Happy" & "Joy" close; "Happy" & "Toolbox" are not

- For each competition, calculate within-topic dispersion of proposal embeddings.
  - Bigger dispersion = Higher topic's non-specificity score

▸ Details

Testing Non-specificity: Results

Panel A: The Role of Topic Specificity in Conventional Topics

	Any Patent		Any High Citation Patent		Any High Originality Patent	
	(1)	(2)	(3)	(4)	(5)	(6)
$\mathbb{1}$(Award)	-0.022	-0.007	-0.036*	-0.013	-0.028	-0.011
	(0.024)	(0.015)	(0.019)	(0.011)	(0.020)	(0.012)
$\mathbb{1}$(Award) $\times$ Non-specificity	0.055**	0.040**	0.038**	0.045***	0.046**	0.023*
	(0.025)	(0.017)	(0.018)	(0.014)	(0.022)	(0.014)
Observations	7384	17500	7384	17500	7384	17500
Proposals	First	All	First	All	First	All
Outcome Mean	0.158	0.253	0.076	0.118	0.103	0.177

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