OPENing up Military Innovation: Causal effects of Reforms to U.S. Defense Research

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Motivation I: How do organizations incentivize innovation?

- Urgent need for growth & innovation in context of COVID & long-term productivity growth slowdown (Decker et al. 2016, Syverson, 2017)

- We focus on one relatively overlooked but crucial choice dimension (Azoulay and Li, 2020):
  - Whether to take a **centralized** “top-down” approach soliciting a particular technology
  - Or a more open, decentralized “**bottom-up**” approach in which innovators suggest ideas, reflecting the organization’s uncertainty over what opportunities exist

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- We compare these two R&D procurement strategies using a reform to the **Small Business Innovation Research** (SBIR) program at the U.S. Air Force (USAF)

Motivation II: Why is defense R&D interesting?

- In US, 60% of all Federal R&D goes to Dept of Defense (DoD): world's largest R&D supporting entity (6% of global R&D)
  - **Dual-use** aspect of frontier defense technology: large spillovers to private sector (e.g. GPS, cryptography, nuclear power, jet engines, Internet,..)
  - US DoD lauded as successful Mission-Oriented Industrial Policy. Evidence from case studies (e.g. Mowery & Rosenberg, 1991; Mazzucato and Semieniuk, 2017)

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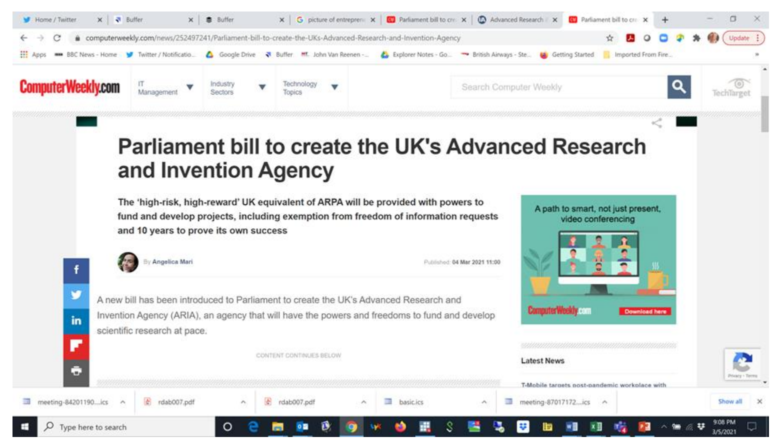

Motivation: Why is defense R&D interesting?

- But all is not well in US Defense Innovation….
  - Bloom, Jones, Van Reenen & Webb (2020): R&D productivity falling for decades. May be because increasingly hard to know what good ideas are out there
  - Defense innovation in decline relative to rest of economy

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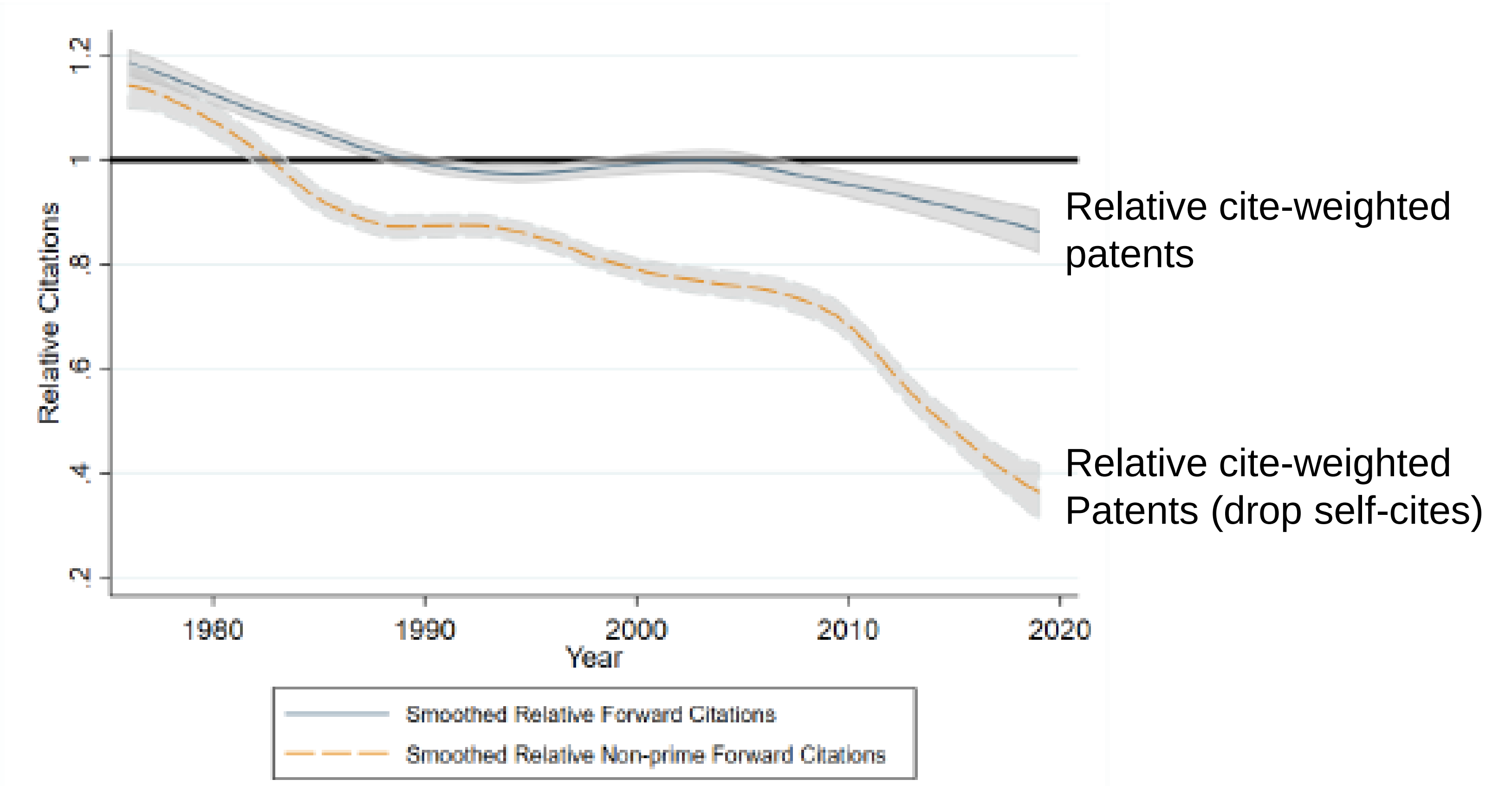
- *“The U.S. government no longer has the leading edge developing its own capabilities, particularly in information technology.”*

  Michael Dumont, Deputy Assistant Sec. of Defense

- *“The swift emergence of information-based technologies as decisive enablers of advanced military capabilities are largely developed and produced outside of the technologically isolated defense industrial base”*

  Under Secretary of Defense memo (Griffin, 2019)

Fig 1: Defense firms go from 20% more innovative than average in 1976 to 10%-40% *less* innovative by 2019



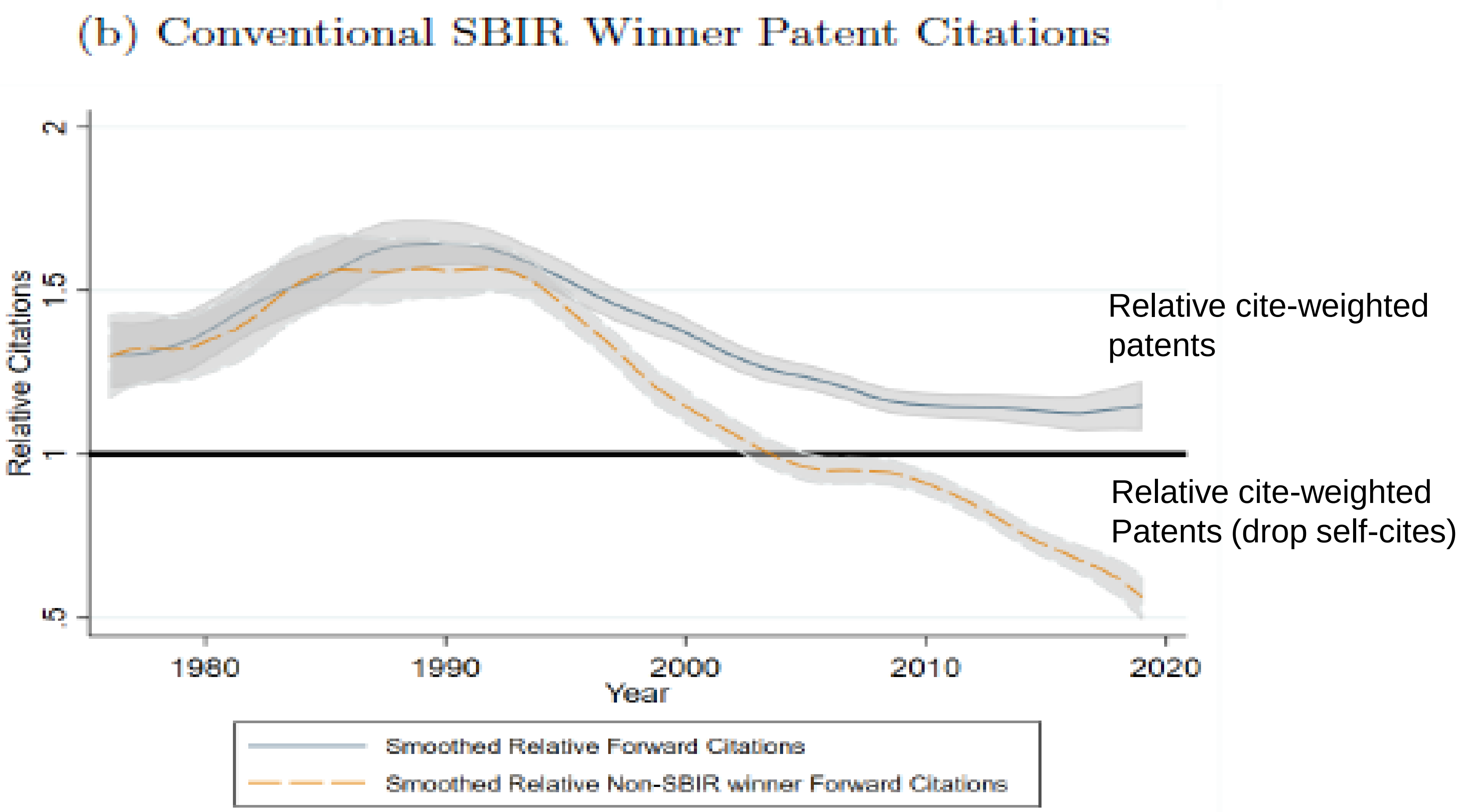
Notes: *Patents weighted by future citations in six "Prime" defense contractors (Lockheed Martin, Boeing, Raytheon/UTC; Harris/L3; Northrop-Grumman, General Dynamics) & all their post 1976 acquisitions. Innovation measures relative to other firms in same technology-class by year (so 1.2 means 20% higher relative innovation rate). Dashed line drops all self-cites.*

USPTO.

Motivation: SBIR in defense R&D

- SBIR program one of world's largest & most influential government small business innovation programs
  - $3.11 billion across 11 Federal agencies in 2018
  - Of this, DoD accounted for $1.32 billion
  - Of this, Air Force had largest single program, $664 million
  - DoD SBIR also shows decline in innovation impact

Declining relative innovation for DoD SBIR winners



Notes: *Patents weighted by future citations among Air Force ABIR winners. Innovation measures relative to other firms in same technology-class by year (so 1.2 means 20% higher relative innovation rate). Dashed line drops all self-cites from other SBIR winner. Kernel smoothed. 95% confidence intervals shown in grey.*

US Air Force reforms: OPEN Topics

- USAF leaders believe that part of declining innovation was an excessively "Top Down" Approach to (Cox et al., 2014; Griffin, 2019). In **Conventional** competitions:
  - Procurement narrowly specified
  - Siloed in a small group of defense-specialist firms. Little "bottom-up" innovation with broad private sector collaboration
  - Too little radical thinking on "tough tech" problems

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  - Too little radical thinking on "tough tech" problems
- 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
- **In 2018** USAF reformed SBIR into new **OPEN Topics** program, which took a decentralized innovation model (increasingly popular in private sector, e.g. Unilever)

Summary of Paper

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Key Findings:

- Open attracted more **new entrants** – e.g. young firms & those that had never applied for SBIR in the past
- RDD: **Open has better outcomes than Conventional**: VC Funding; non-SBIR DoD contracts (tech adoption); Patenting
- Conv. “better” only for future SBIR contracts (lock-in by “mills”)

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Mechanism:

- Partly through attraction of firms with higher treatment effects
- Partly through **bottom up** innovation: (i) compare to other reform programs; (ii) **less tightly specified** (defined using machine learning) Conventional topics also more successful

Cost-Benefit:

- Welfare analysis suggests important net benefits from more bottom up innovation via Open

Some Existing Literature

- **Motivating Innovation** Azoulay et al ’11, Nanda et al ’14, Krieger ’18, Azoulay & Li ’20, Chesbrough ’03 (“Open”)
- **Procurement & Innovation** Nalebuff & Stiglitz ’83, Rogerson ’89; Lichtenberg ’95, Jacobsen ’15; Gonzalez-Lira et al ‘21
- **Impact of defense R&D**. ***Demand*****:** Barro & Redlick ’11; Ramey ’11, Perotti ’14, Nakamura & Steinsson ’15, ***R&D Crowd-out/in*****:** Lichtenberg, ‘84, ’88; Moretti et al, ’20, Carril & Duggan ’20;***Innovation*****:** Draca ’13, Akcigit et al ’17
- **Evaluation of innovation policies** Most on government as subsidizer rather than as procurer (Belenzon & Cioaca ’21). ***Tax*****:** Hall ’93, Bloom et al ’02, Wilson ’09, Chen et al ’17, Moretti & Wilson ’17, Akcigit et al ‘18; Dechezlepetre et al ’20, Akcigit & Stantcheva ‘21; ***Subsidies*****:** Jacob & Lefgren ‘10, Takalo et al ’13, Bronzini & Iachini ’14, Azoulay et al ’19, Fleming et al ‘19; ***interactions*****:** Pless ’19
- **SBIR** Lerner ’99, Wallsten ’00, Howell ’17, Lanahan & Feldman ’18, **Bhattacharya,’21**, Brown & Howell, ‘20

Outline

- **Institutional background**
- Data
- Econometric Strategy
- Baseline Results
- Mechanisms
- Cost Benefit & Conclusions

US Air Force SBIR reforms

- 2018 Reforms to USAF SBIR program. Goals:
  - Reach non-traditional firms with frontier dual-use tech
  - Source ideas for USAF that it may not yet know it needs: "Unknown unknowns"
  - Revive USAF role as a large, early customer for risky new technologies from new firms
- **Conventional Topics**: Highly Specified: e.g. *"Safe, Large-Format Lithium-ion Batteries for ICBMs"*
  - $150,000 if win Phase I

Safe, Large-Format Lithium-ion (Li-ion) Batteries for ICBMs

Agency:	Department of Defense
Branch:	Air Force
Program | Phase | Year:	SBIR | BOTH | 2018
Solicitation:	DoD 2018.1 SBIR Solicitation
Topic Number:	AF181-046

NOTE: The Solicitations and topics listed on this site are copies from the various SBIR agency solicitations and are not necessarily the latest and most up-to-date. For this reason, you should use the agency link listed below which will take you directly to the appropriate agency server where you can read the official version of this solicitation and download the appropriate forms and rules.

The official link for this solicitation is: https://www.acq.osd.mil/osbp/sbir/solicitations/index.shtml

Release Date:	Open Date:	Application Due Date:	Close Date:
November 29, 2017	January 08, 2018	February 07, 2018	February 07, 2018

Some Other Examples of Conventional Topics

- *“Affordable, Durable, Electrically Conductive Coating or Material Solution for Silver Paint Replacement on Advanced Aircraft"*
- *“Mitigation of Scintillation and Speckle for Tracking Moving Targets”*
- *“Develop Capability to Measure the Health of High Impedance Resistive Materials”*
- *“Standalone Non-Invasive Sensing of Cyber Intrusions in FADEC for Critical Aircraft System Protection”*
- *“Hypersonic Vehicle Electrical Power Generation through Efficient Thermionic Conversion Devices”*
- *“Cyber Attack model using game theory”*

US Air Force SBIR reforms: OPEN Topics

- **Conventional Topics**: Highly Specified: e.g. *“Safe, Large-Format Lithium-ion Batteries for ICBMs”*
  – $150,000 if win
- **Open Topics** Non-specific Call *for “Innovative Defense-Related Dual-Purpose Technologies with a clear USAF Need”*
  – $50,000 if win

- In both, winners of *Phase I* must deliver a White Paper/Proof of Concept. Can then enter Phase II competition to develop prototype (~50% Phase I winners win Phase II)

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Data

- Administrative data on 21,432 proposals 2003-19. Winners in public domain, but applicants & scores are not

- Focus on 2017-19 when Open & Conventional overlap
  - 6,654 proposals (1,659 Open & 4,995 Conventional)
  - 428 competitions (6 Open & 422 Conventional)
  - 3,059 unique firms

Who wins?

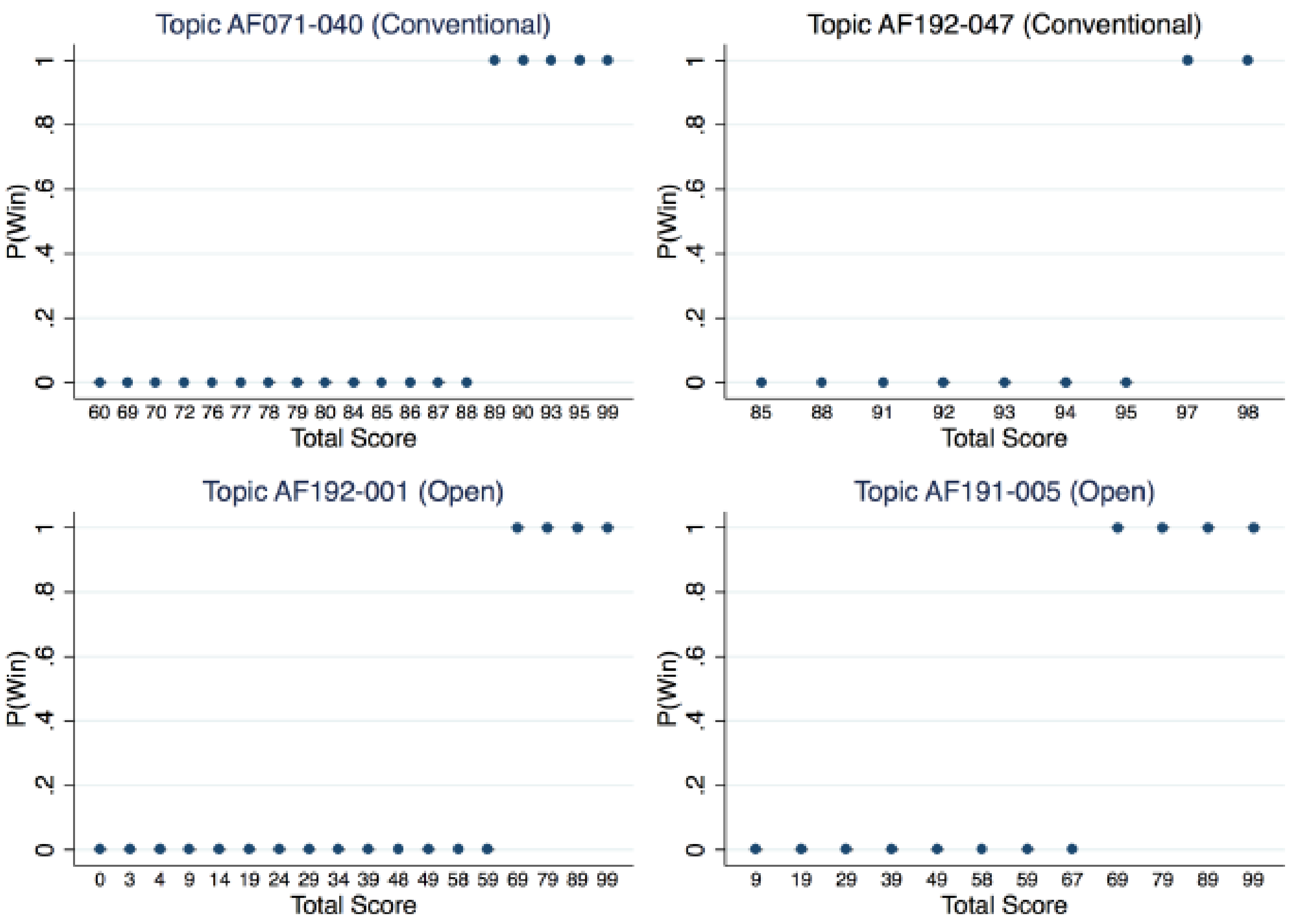
- For all competitions, three USAF staff evaluators give a sub-score. Each gives a single sub-score (0-33) on their area of expertise:
  - Commercial
  - Team
  - Technical

- These are summed to give the overall score and all applicants ranked. Total budget determines where threshold rank is (different by competition and determined *ex ante*)

- Cost not a factor in evaluation

Sharp Discontinuity

Figure 3: Raw Scores and Award Probability in Four Representative Topics



Note: These plots document the sharp RDD in each topic by showing the probability of winning by raw score. The score perfectly predicts award except occasionally when an awardee is declined in the contracting process because some ineligibility was identified (these instances are dropped in analysis). Note that the range of scores differs across topics, which is we construct a rank normalization for combined analysis.

Data: Main Outcomes

- Discussions with DoD two main outcomes they focus on:

1. Future Venture Capital (VC) Funding

  – VC interest indicates dual use of military tech in private sector. VC backed firms signal innovative potential (Lerner and Nanda, 2020, 44% of all R&D in publicly listed firms)
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2. Future non-SBIR DoD contracts (tech adoption)

- – Military refer to these as *"transitions to programs of record".* Contracts signal that the technology has gone from R&D stage in SBIR to a tangible output that DoD can develop
- – Federal Procurement Data System (DUNS, name, location). Focus on >$50k contracts
- – *Example:* Aevum won Open award (7/19) for a design for drone-launched rockets in a former textile mill. On back of this got a $4.9m Air Force contract.

Data: Ancillary Outcomes:

- Future **patenting** (USPTO)
  - **Any**
  - Cites, Originality, Generality, Application counts, etc.

- Future **SBIR contracts**

- Baseline results follow these outcomes in window over next 24 months after an award, but also look at longer windows (e.g. ever) and shorter windows (e.g. 12 months)

Table 1: Big differences in characteristics of firms applying to Open vs. Conventional Topics

	Open	Conventional
	N=1,659	N=4,995
Firm Age (years)	9.8 [*5*]	18.2 [*15*]
Size (Number Employees)	26.9 [*8*]	60.8 [*20*]
Located in VC hub	19.7%	14.8%
Located in county near AF base	19.2%	27.5%

Note: These are means [*medians*] from all Open and Conventional Phase 1 applications between 2017 and 2019.

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Pre-award VC	11.4%	6%
Pre-award DoD non-SBIR contract	25.3%	60.1%
Pre-award Patent	25%	47.3%
Pre-award SBIR contract	23%	66.6%

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Pre-award SBIR contract	23%	66.6%
Number of proposals per topic	379 [*375*]	20 [*15*]
Number of winners per topic	213 [*297*]	3[*2*]

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Econometric model

- Regression Discontinuity Design (RDD) based on normalized rank of proposal *i* for competition topic *T* ($Rank_{iT}$ = 0 for threshold)

Topic fixed effects

Treatment effect

Running variable

$$Y_{iT} = \alpha_T + \beta\,[1|Rank_{iT} > 0] + \gamma_1[Rank_{iT}|Rank_{iT} > 0] + \gamma_2[Rank_{iT}|Rank_{iT} < 0] + \delta PSBIRi + \varepsilon_{iT}$$

Dummy for winning previous SBIR

Econometric model

- Also look at models pooling across competitions to examine whether outcomes are significantly different across (Open vs. Conventional in main results)

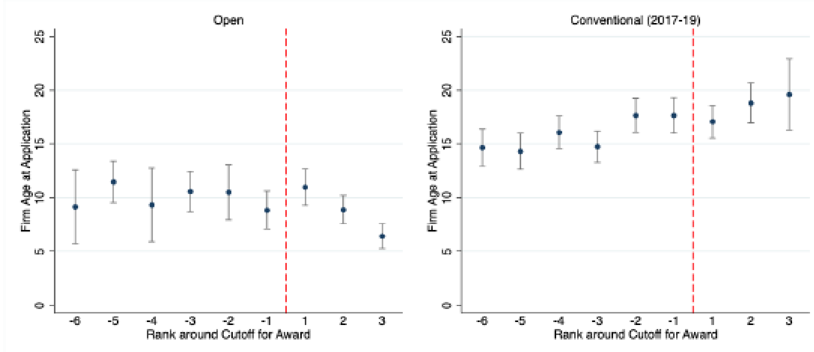
$$
\begin{aligned}
Y_{iT} = \alpha_T + \beta\,[1|Rank_{iT} > 0] \cdot \mathbf{Program}'_{\mathbf{T}} \\
+ \gamma_1[Rank_{iT}|Rank_{iT} > 0] \cdot \mathbf{Program}'_{\mathbf{T}} \\
+ \gamma_2\,[Rank_{iT}|Rank_{iT} < 0] \cdot \mathbf{Program}'_{\mathbf{T}} \\
+ \delta PSBIRi \cdot \mathbf{Program}'_{\mathbf{T}} + \varepsilon_{iT}
\end{aligned}
$$

Diagnostics

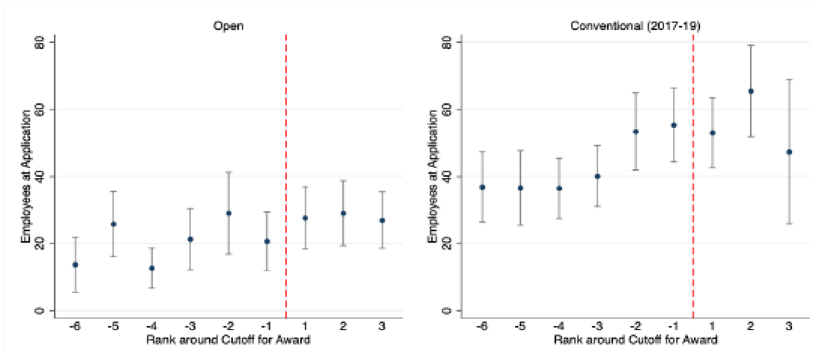
- Covariate Balance (Fig A14-A17)
- Smooth density around threshold (Fig 4)
- Three separate evaluators manipulation hard: sub-scores not highly correlated (Figure A18)

Figure A.14: Continuity of Baseline Characteristics by Rank around Cutoff (Part 1 of 4)

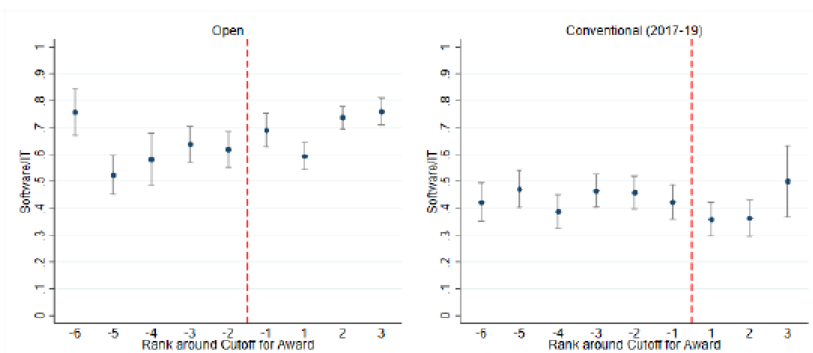
(a) Firm Age at Application



(b) Firm Employment at Application



(c) Software vs. Hardware Technology

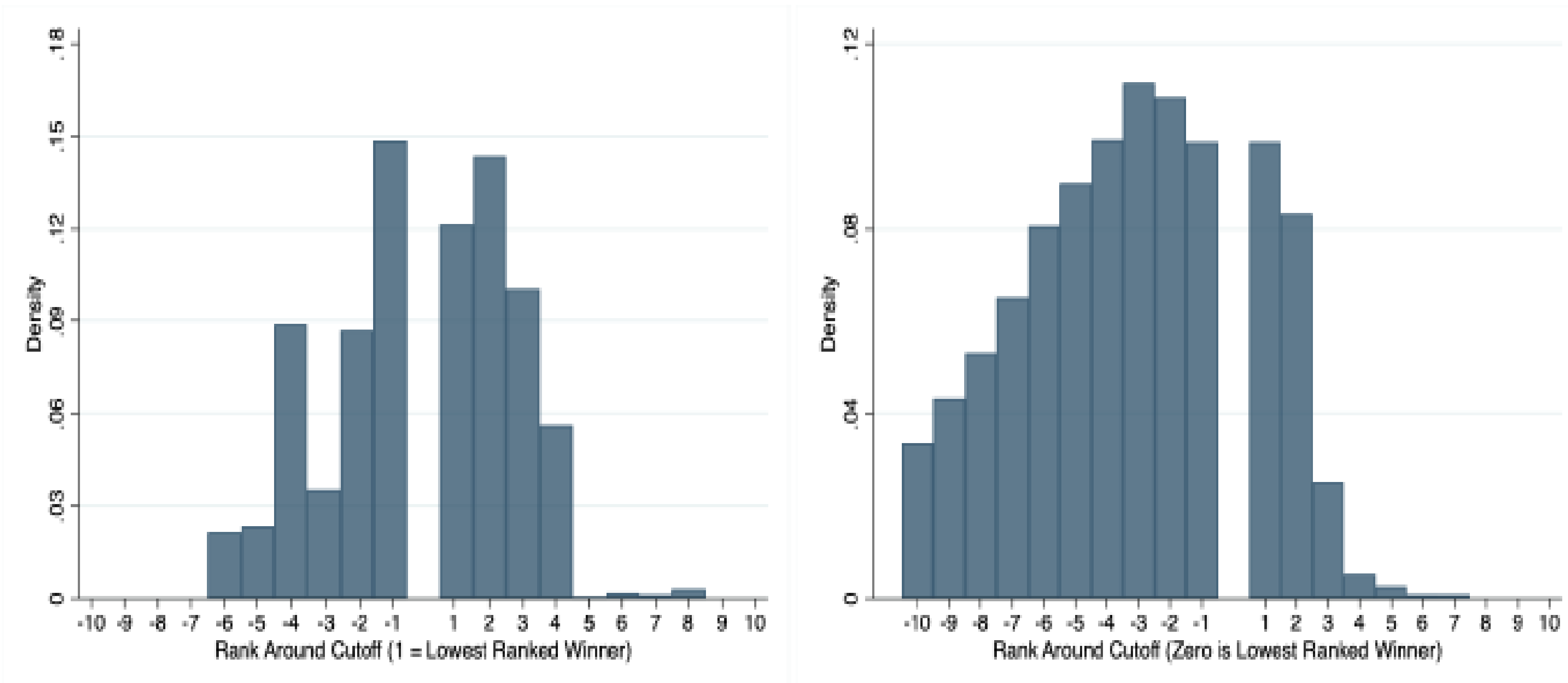


Note: These figures show applicant firm age (top figures), employment (middle figures), and the k-means 2 cluster abstract classification which yields a software and a hardware group (bottom figures) at the time of the application. In all cases, the x-axis shows the applicant's rank around the cutoff for an award. A rank of 1 indicates that the applicant had the lowest score among winners, while a rank of -1 indicates that the applicant had the highest score among losers. The grey capped lines represent 95% confidence intervals.

Figure 4: Regression Discontinuity Density Manipulation Test

(a) Open

(b) Conventional (2017-19)



Note: This figure plots the density of applicants by rank around the cutoff using Phase 1 applicants to the Open (left graph labeled (a)) and Conventional (right graph labeled (b)) programs, to test for bunching near the cutoff. There is more density overall to the left of the cutoff because there are more losers than winners.

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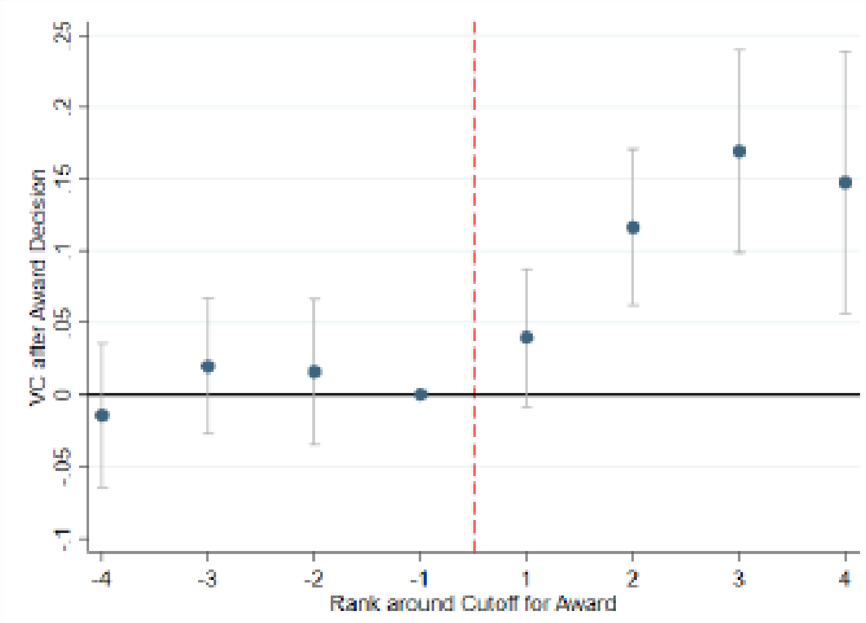
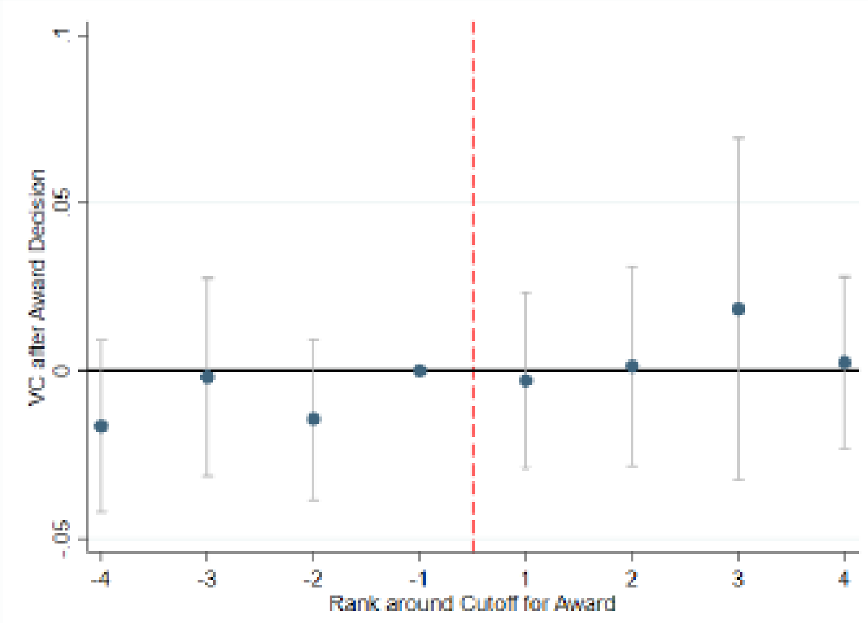
Figure 5: Probability of Venture Capital by Rank Around Cutoff

(a) Open



(b) Conventional (2017-19)



Note: These figures show the probability that an applicant firm raised venture capital investment (VC) within 24 months after the award decision. In both panels, the x-axis shows the applicant's rank around the cutoff for an award. A rank of 1 indicates that the applicant had the lowest score among winners, while a rank of -1 indicates that the applicant had the highest score among losers. We plot the points and 95% confidence intervals from a regression of the outcome on a full complement of dummy variables representing each rank, as well as fixed effects for the topic. The omitted group is rank=-1. We include first applications from 2017-19.

Table 2: Effect of Winning on Main Outcomes

Panel A: Any Subsequent Venture Capital Investment

	(1)	(2)	(3)	(4)	(5)	(6)
$\mathbb{1}$(Award)	0.052**	-0.006	0.010	-0.006	0.010	0.005
	(0.026)	(0.021)	(0.010)	(0.020)	(0.010)	(0.003)
$\mathbb{1}$(Award) × $\mathbb{1}$(Open Topic)				0.058**	0.042*	0.046**
				(0.029)	(0.024)	(0.021)
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	0.086	0.019	0.017	0.042	0.028	0.017

Note: This table shows regression discontinuity (RD) estimates of the effect of winning a Phase 1 award on the probability of any VC investment (Panel A) and any non-SBIR DoD contract valued at more than \$50,000 (Panel B) within 24 months after the award decision for Open topics and Conventional topics. Rank within the topic (competition) is controlled separately as a linear function on either side of the cutoff. In all cases, we control for previous Air Force SBIR awards. Columns (1) to (3) estimate the effect of winning separately for each program. Column (1) contains estimates of the effect of winning an Open topic. Columns (2) and (3) contain estimates of the effect of winning a Conventional topic for years between 2017-19 and 2003-19, respectively. Columns (4) through (6) pool both Open and Conventional programs and interact winning an award with an indicator that is equal to one if a proposal is in an Open topic (and zero otherwise). Column (4) restricts the sample to the years between 2017-2019 and columns (5) and (6) include all years 2003-19. Columns (1) through (5) restrict the sample to the firm's first application within the sample time period whereas column (6) uses all proposals. All columns include topic fixed effects. Standard errors are below coefficients (in parentheses) and are clustered by firm in columns (1) through (3) and by topic in columns (4) through (6). ***, **, * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

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$\mathbb{1}$(Award) × $\mathbb{1}$(Open Topic)				0.058**	0.042*	0.046**
				(0.029)	(0.024)	(0.021)
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	0.086	0.019	0.017	0.042	0.028	0.017

Note: This table shows regression discontinuity (RD) estimates of the effect of winning a Phase 1 award on the probability of any VC investment (Panel A) and any non-SBIR DoD contract valued at more than $50,000 (Panel B) within 24 months after the award decision for Open topics and Conventional topics. Rank within the topic (competition) is controlled separately as a linear function on either side of the cutoff. In all cases, we control for previous Air Force SBIR awards. Columns (1) to (3) estimate the effect of winning separately for each program. Column (1) contains estimates of the effect of winning an Open topic. Columns (2) and (3) contain estimates of the effect of winning a Conventional topic for years between 2017-19 and 2003-19, respectively. Columns (4) through (6) pool both Open and Conventional programs and interact winning an award with an indicator that is equal to one if a proposal is in an Open topic (and zero otherwise). Column (4) restricts the sample to the years between 2017-2019 and columns (5) and (6) include all years 2003-19. Columns (1) through (5) restrict the sample to the firm's first application within the sample time period whereas column (6) uses all proposals. All columns include topic fixed effects. Standard errors are below coefficients (in parentheses) and are clustered by firm in columns (1) through (3) and by topic in columns (4) through (6). ***, **, * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Table 2: Effect of Winning on Main Outcomes

Panel A: Any Subsequent Venture Capital Investment

	(1)	(2)	(3)	(4)	(5)	(6)
$\mathbb{1}$(Award)	0.052**	-0.006	0.010	-0.006	0.010	0.005
	(0.026)	(0.021)	(0.010)	(0.020)	(0.010)	(0.003)
$\mathbb{1}$(Award) × $\mathbb{1}$(Open Topic)				0.058**	0.042*	0.046**
				(0.029)	(0.024)	(0.021)
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	0.086	0.019	0.017	0.042	0.028	0.017

Note: This table shows regression discontinuity (RD) estimates of the effect of winning a Phase 1 award on the probability of any VC investment (Panel A) and any non-SBIR DoD contract valued at more than $50,000 (Panel B) within 24 months after the award decision for Open topics and Conventional topics. Rank within the topic (competition) is controlled separately as a linear function on either side of the cutoff. In all cases, we control for previous Air Force SBIR awards. Columns (1) to (3) estimate the effect of winning separately for each program. Column (1) contains estimates of the effect of winning an Open topic. Columns (2) and (3) contain estimates of the effect of winning a Conventional topic for years between 2017-19 and 2003-19, respectively. Columns (4) through (6) pool both Open and Conventional programs and interact winning an award with an indicator that is equal to one if a proposal is in an Open topic (and zero otherwise). Column (4) restricts the sample to the years between 2017-2019 and columns (5) and (6) include all years 2003-19. Columns (1) through (5) restrict the sample to the firm's first application within the sample time period whereas column (6) uses all proposals. All columns include topic fixed effects. Standard errors are below coefficients (in parentheses) and are clustered by firm in columns (1) through (3) and by topic in columns (4) through (6). ***, **, * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

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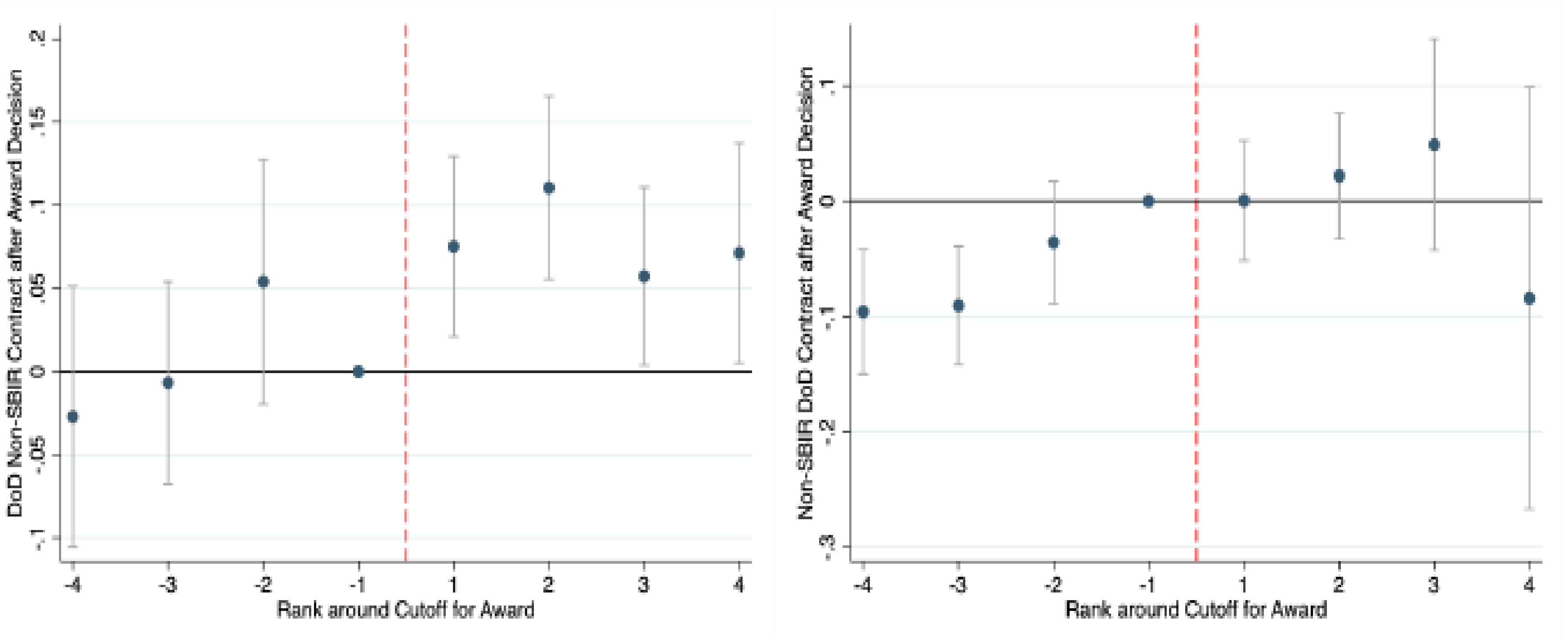
Panel A: Any Subsequent Venture Capital Investment

	(1)	(2)	(3)	(4)	(5)	(6)
$\mathbb{1}$(Award)	0.052**	-0.006	0.010	-0.006	0.010	0.005
	(0.026)	(0.021)	(0.010)	(0.020)	(0.010)	(0.003)
$\mathbb{1}$(Award) × $\mathbb{1}$(Open Topic)				0.058**	0.042*	0.046**
				(0.029)	(0.024)	(0.021)
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	0.086	0.019	0.017	0.042	0.028	0.017

Note: This table shows regression discontinuity (RD) estimates of the effect of winning a Phase 1 award on the probability of any VC investment (Panel A) and any non-SBIR DoD contract valued at more than $50,000 (Panel B) within 24 months after the award decision for Open topics and Conventional topics. Rank within the topic (competition) is controlled separately as a linear function on either side of the cutoff. In all cases, we control for previous Air Force SBIR awards. Columns (1) to (3) estimate the effect of winning separately for each program. Column (1) contains estimates of the effect of winning an Open topic. Columns (2) and (3) contain estimates of the effect of winning a Conventional topic for years between 2017-19 and 2003-19, respectively. Columns (4) through (6) pool both Open and Conventional programs and interact winning an award with an indicator that is equal to one if a proposal is in an Open topic (and zero otherwise). Column (4) restricts the sample to the years between 2017-2019 and columns (5) and (6) include all years 2003-19. Columns (1) through (5) restrict the sample to the firm's first application within the sample time period whereas column (6) uses all proposals. All columns include topic fixed effects. Standard errors are below coefficients (in parentheses) and are clustered by firm in columns (1) through (3) and by topic in columns (4) through (6). ***, **, * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Figure 6: Probability of DoD non-SBIR Contract by Rank Around Cutoff

(a) Open (b) Conventional (2017-19)



Note: These figures show the probability that an applicant firm had any non-SBIR DoD contracts valued at more than $50,000 within 24 months after the award decision. In both panels, the x-axis shows the applicant's rank around the cutoff for an award. A rank of 1 indicates that the applicant had the lowest score among winners, while a rank of -1 indicates that the applicant had the highest score among losers. We plot the points and 95% confidence intervals from a regression of the outcome on a full complement of dummy variables representing each rank, as well as fixed effects for the topic. The omitted group is rank=-1. We include first applications from 2017-19.

Table 2B: DoD Non-SBIR Contracts (technology implementation by Department of Defense)

Panel B: Any Subsequent Non-SBIR DoD Contracts

	(1)	(2)	(3)	(4)	(5)	(6)
$\mathbb{1}$(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)
$\mathbb{1}$(Award) × $\mathbb{1}$(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

Note: This table shows regression discontinuity (RD) estimates of the effect of winning a Phase 1 award on the probability of any VC investment (Panel A) and any non-SBIR DoD contract valued at more than $50,000 (Panel B) within 24 months after the award decision for Open topics and Conventional topics. Rank within the topic (competition) is controlled separately as a linear function on either side of the cutoff. In all cases, we control for previous Air Force SBIR awards. Columns (1) to (3) estimate the effect of winning separately for each program. Column (1) contains estimates of the effect of winning an Open topic. Columns (2) and (3) contain estimates of the effect of winning a Conventional topic for years between 2017-19 and 2003-19, respectively. Columns (4) through (6) pool both Open and Conventional programs and interact winning an award with an indicator that is equal to one if a proposal is in an Open topic (and zero otherwise). Column (4) restricts the sample to the years between 2017-2019 and columns (5) and (6) include all years 2003-19. Columns (1) through (5) restrict the sample to the firm's first application within the sample time period whereas column (6) uses all proposals. All columns include topic fixed effects. Standard errors are below coefficients (in parentheses) and are clustered by firm in columns (1) through (3) and by topic in columns (4) through (6). ***, **, * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Table 2B: DoD Non-SBIR Contracts (technology implementation by Department of Defense)

Panel B: Any Subsequent Non-SBIR DoD Contracts

	(1)	(2)	(3)	(4)	(5)	(6)
$\mathbb{1}$(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)
$\mathbb{1}$(Award) × $\mathbb{1}$(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
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Table 2B: DoD Non-SBIR Contracts (technology implementation by Department of Defense)

Panel B: Any Subsequent Non-SBIR DoD Contracts

	(1)	(2)	(3)	(4)	(5)	(6)
$\mathbb{1}$(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)
$\mathbb{1}$(Award) × $\mathbb{1}$(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
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Magnitude of the main effects

- Why such a large effect from Open? (a small $50,000 grant)

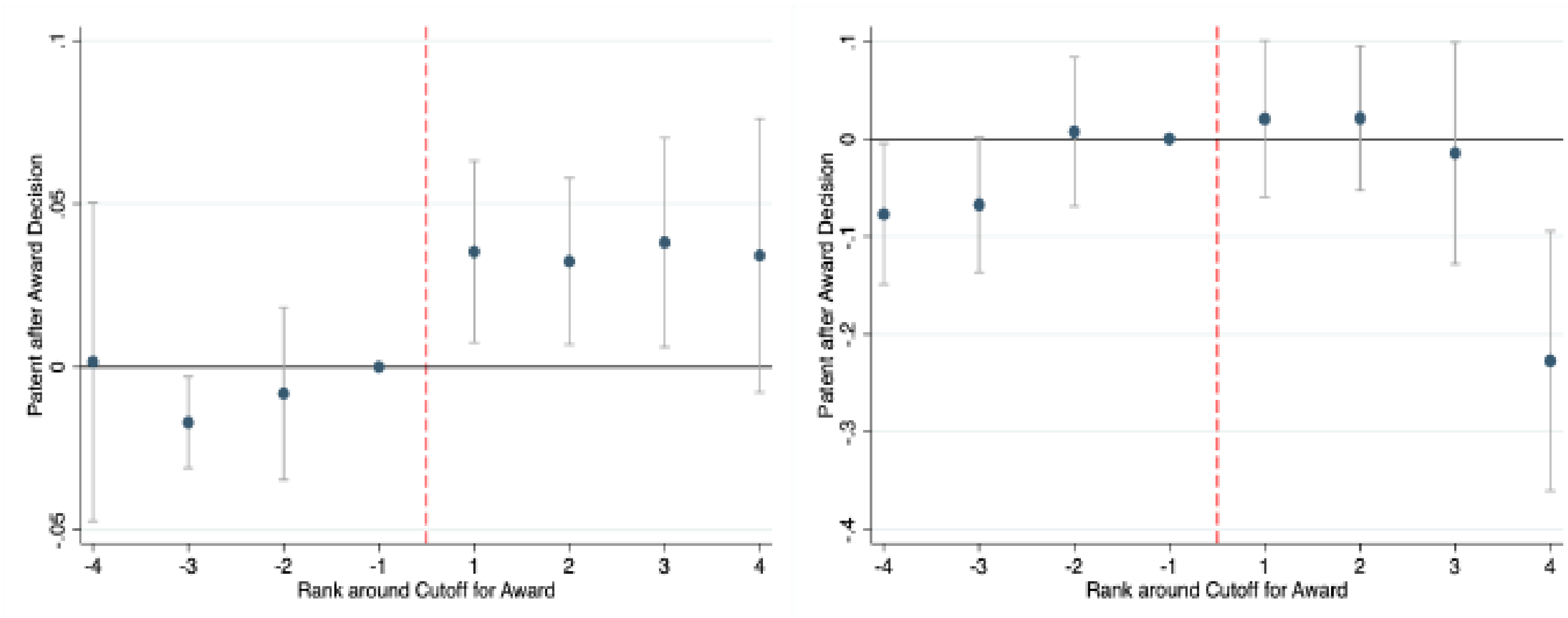
- Phase 1 winners have a high probability of winning Phase 2 (average value ~$800,000). About half of Phase 1 winners also win Phase 2

- Signal of winning Open implies good chance of subsequent DoD contract (average value ~$1.7 million), which is attractive for VCs

- What about other outcomes? Look at patenting and SBIR contracts

Figure 7: Probability of Patents by Rank Around Cutoff

(a) Open (b) Conventional (2017-19)



Note: These figures show the probability that an applicant firm had any ultimately granted patent applications within 24 months after the award decision. In both panels, the x-axis shows the applicant's rank around the cutoff for an award. A rank of 1 indicates that the applicant had the lowest score among winners, while a rank of -1 indicates that the applicant had the highest score among losers. We plot the points and 95% confidence intervals from a regression of the outcome on a full complement of dummy variables representing each rank, as well as fixed effects for the topic. The omitted group is rank=-1.We include first applications from 2017-19.

Table 3: Effect of Winning on Ancillary Outcomes

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

Note: This table shows regression discontinuity (RD) estimates of the effect of winning a Phase 1 award on the probability of any ultimately granted patent applications (Panel A) and any SBIR DoD contracts (Panel B) within 24 months after the award decision for Open topics and Conventional topics. Rank within the topic (competition) is controlled separately as a linear function on either side of the cutoff. In all cases, we control for previous Air Force SBIR awards. Columns (1) through (3) contain estimates of the effect of winning separately for each program. Column (1) contains estimates of the effect of winning an Open topic. Columns (2) and (3) estimate the effect of winning a Conventional topic for years between 2017-19 and 2003-19, respectively. Columns (4) through (6) pool both Open and Conventional programs and interact winning an award with an indicator that is equal to one if a proposal is in an Open topic (and zero otherwise). Column (4) restricts the sample to the years between 2017-2019 and columns (5) and (6) include all years 2003-19. Columns (1) through (5) restricts the sample to the firm's first application within the sample time period; whereas column (6) uses all proposals. All columns include topic fixed effects. Standard errors are below coefficients (in parentheses) and are clustered by firm in columns (1) through (3) and by topic in columns (4) through (6). ***, **, * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

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	(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) × $\mathbb{1}$(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
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	(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
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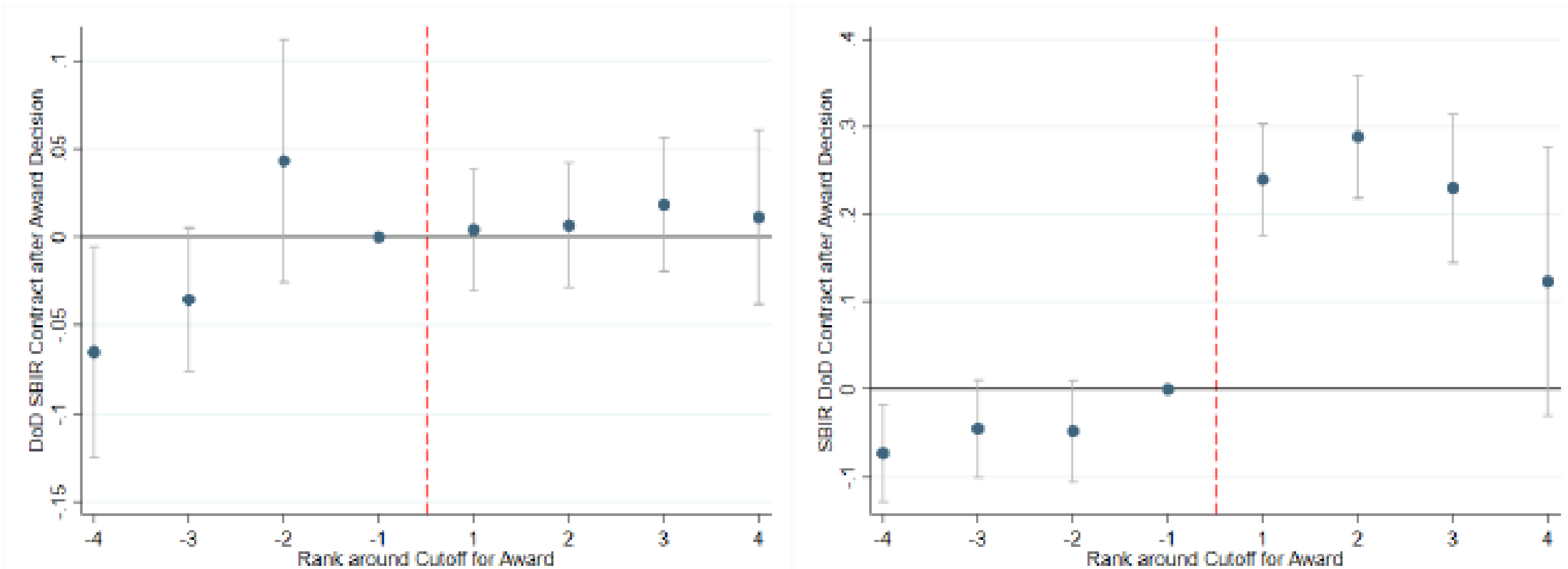
Figure 8: Probability of Air Force SBIR Contract by Rank Around Cutoff

(a) Open (b) Conventional



Note: These figures show the probability that an applicant firm had any Air Force SBIR contracts within 24 months after the award decision. In both panels, the x-axis shows the applicant's rank around the cutoff for an award. A rank of 1 indicates that the applicant had the lowest score among winners, while a rank of -1 indicates that the applicant had the highest score among losers. We plot the points and 95% confidence intervals from a regression of the outcome on a full complement of dummy variables representing each rank, as well as fixed effects for the topic. The omitted group is rank=-1. We include all data for Conventional rather than only 2017-19 because the effect is only observed in the whole sample, as the sample in 2017-19 is overwhelmingly repeat-firms.

Table 3, Panel B: Future SBIR Contracts

Panel B: Any Subsequent SBIR Contracts

	(1)	(2)	(3)	(4)	(5)	(6)
$\mathbb{1}$(Award)	0.012	0.137***	0.171***	0.137***	0.171***	0.059***
	(0.022)	(0.049)	(0.027)	(0.048)	(0.027)	(0.011)
$\mathbb{1}$(Award) $\times$ $\mathbb{1}$(Open Topic)				-0.125**	-0.159***	-0.056***
				(0.049)	(0.030)	(0.017)
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	0.058	0.283	0.206	0.205	0.183	0.443

Note: This table shows regression discontinuity (RD) estimates of the effect of winning a Phase 1 award on the probability of any ultimately granted patent applications (Panel A) and any SBIR DoD contracts (Panel B) within 24 months after the award decision for Open topics and Conventional topics. Rank within the topic (competition) is controlled separately as a linear function on either side of the cutoff. In all cases, we control for previous Air Force SBIR awards. Columns (1) through (3) contain estimates of the effect of winning separately for each program. Column (1) contains estimates of the effect of winning an Open topic. Columns (2) and (3) estimate the effect of winning a Conventional topic for years between 2017-19 and 2003-19, respectively. Columns (4) through (6) pool both Open and Conventional programs and interact winning an award with an indicator that is equal to one if a proposal is in an Open topic (and zero otherwise). Column (4) restricts the sample to the years between 2017-2019 and columns (5) and (6) include all years 2003-19. Columns (1) through (5) restricts the sample to the firm's first application within the sample time period; whereas column (6) uses all proposals. All columns include topic fixed effects. Standard errors are below coefficients (in parentheses) and are clustered by firm in columns (1) through (3) and by topic in columns (4) through (6). ***, **, * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

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	(1)	(2)	(3)	(4)	(5)	(6)
$\mathbb{1}$(Award)	0.012	0.137***	0.171***	0.137***	0.171***	0.059***
	(0.022)	(0.049)	(0.027)	(0.048)	(0.027)	(0.011)
$\mathbb{1}$(Award) × $\mathbb{1}$(Open Topic)				-0.125**	-0.159***	-0.056***
				(0.049)	(0.030)	(0.017)
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
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Summary of RDD results

- *Winning* **Open** SBIR USAF competition has significant positive causal effects on future innovation (VC, patenting) and translating this R&D into military technology (i.e. obtaining non-SBIR DoD Contracts)

- *Winning* **Conventional** has no causal effects on these outcomes, but *does* increase chances of obtaining future SBIR contract (creating lock-in)

Robustness (Table 4)

- **Did Open crowd out Conventional?**
  - No: get same results for Conventional in 2015-17 when no Open Competitions available

Robustness (Table 4)

- **Did Open crowd out Conventional?**
  - No: get same results for Conventional in 2015-17 when no Open Competitions available
- **Specification checks show robustness (Table 4)**
  - Including or dropping controls inc. pre-award outcomes
  - Using a narrow bandwidth around cutoff
  - Using higher order polynomial for rank
  - Define outcomes as “Ever” after win or 12 months instead of 24 month post award window
  - Alternative functional forms for dependent variables: **VC & Contracts** (count, $Value) in Tab A4; **Patents** (Count, Originality; Citations; Generality) in Tab A5
- Magnitude of Conventional (insignificant) effect on patents changes – e.g. smaller when narrow bandwidth

Table 4: Robustness Tests

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)	0.048*	-0.006	0.049***	0.065	0.057*	0.026	0.010	0.155***
	(0.026)	(0.018)	(0.017)	(0.043)	(0.034)	(0.049)	(0.022)	(0.043)
Observations	1385	2608	1385	2608	1385	2608	1385	2608
Program	Open	Conv	Open	Conv	Open	Conv	Open	Conv
Outcome Mean	0.086	0.019	0.027	0.146	0.148	0.324	0.058	0.269

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)	0.058**	-0.007	0.049***	0.081*	0.045	0.040	-0.008	0.170***
	(0.026)	(0.018)	(0.016)	(0.045)	(0.037)	(0.054)	(0.024)	(0.048)
Observations	1385	2608	1385	2608	1385	2608	1385	2608
Program	Open	Conv	Open	Conv	Open	Conv	Open	Conv
Outcome Mean	0.086	0.019	0.027	0.146	0.148	0.324	0.058	0.269

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)	0.064***	0.003	0.037***	0.015	0.072***	0.050	-0.003	0.076**
	(0.020)	(0.010)	(0.013)	(0.031)	(0.027)	(0.034)	(0.016)	(0.032)
Observations	671	902	671	902	671	902	671	902
Program	Open	Conv	Open	Conv	Open	Conv	Open	Conv
Outcome Mean	0.064	0.017	0.021	0.216	0.153	0.434	0.062	0.409

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**	0.001	0.047***	0.067**	0.088***	0.011	0.003	0.080**
	(0.024)	(0.011)	(0.015)	(0.031)	(0.033)	(0.035)	(0.021)	(0.035)
Observations	1659	4995	1659	4995	1659	4995	1659	4995
Program	Open	Conv	Open	Conv	Open	Conv	Open	Conv
Outcome Mean	0.086	0.014	0.028	0.142	0.160	0.467	0.063	0.420

Most sensitive coefficient is patents for conventional – smaller in narrower bandwidth

Outline

- Institutional background
- Data
- Econometric Strategy
- Results
- **Mechanisms**
- Cost Benefit & Conclusions

Mechanism

- Why does Open have causal effects on outcomes USAF cares about when Conventional does not?

- Use several designs to investigate mechanisms
  - **Selection:** Open attracted firms with larger treatment effects. *Test:* Look at treatment effect heterogeneity

  - **Decentralized:** Bottom Up nature of Open competitions meant that firms came up with more successful ideas. *Tests:*
    1. Look at degrees of “non-specificity” in the Conventional program. Did the less specific Conventional competitions have positive effects like Open?
    2. Look at other reformed program reforms that also attracted new entrants

Table 5: Heterogeneity in Effect of Winning on Venture Capital Investment

	(1)	(2)	(3)	(4)
$\mathbb{1}$(Award)	0.063**	0.083***	0.000	-0.008
	(0.026)	(0.028)	(0.026)	(0.024)
$\mathbb{1}$(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)
Observations	1385	1385	2608	2608
Program	Open	Open	Conv.	Conv.
Time Period	2017-19	2017-19	2017-19	2017-19
Outcome Mean	0.079	0.079	0.019	0.019

Note: This table shows regression discontinuity (RD) estimates of the effect of winning a Phase 1 award on the probability of any VC investment within 24 months after the award decision for Open topics (columns (1) - (2)) and Conventional topics (columns (3) - (4)). Rank within the topic (competition) is controlled separately as a linear function on either side of the cutoff. In all cases, we control for previous Air Force SBIR awards. Columns (1) and (3) interact winning an award with an indicator for having won previous Air Force SBIR awards. Columns (2) and (4) interact winning an award with an indicator for a young firm defined as firm's age below the median of the distribution of firm age (and zero otherwise). All columns include topic fixed effects. Standard errors (in parentheses) are below coefficients and are clustered by firm. ***, **, * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Table 5: Heterogeneity in Effect of Winning on Venture Capital Investment

	(1)	(2)	(3)	(4)
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	(0.026)	(0.028)	(0.026)	(0.024)
$\mathbb{1}$(Award) × $\mathbb{1}$(Prev. SBIR)	-0.072***		-0.008	
	(0.027)		(0.018)	
$\mathbb{1}$(Award) × $\mathbb{1}$(High Age)		-0.098***		0.004
		(0.026)		(0.017)
Observations	1385	1385	2608	2608
Program	Open	Open	Conv.	Conv.
Time Period	2017-19	2017-19	2017-19	2017-19
Outcome Mean	0.079	0.079	0.019	0.019

Note: This table shows regression discontinuity (RD) estimates of the effect of winning a Phase 1 award on the probability of any VC investment within 24 months after the award decision for Open topics (columns (1) - (2)) and Conventional topics (columns (3) - (4)). Rank within the topic (competition) is controlled separately as a linear function on either side of the cutoff. In all cases, we control for previous Air Force SBIR awards. Columns (1) and (3) interact winning an award with an indicator for having won previous Air Force SBIR awards. Columns (2) and (4) interact winning an award with an indicator for a young firm defined as firm's age below the median of the distribution of firm age (and zero otherwise). All columns include topic fixed effects. Standard errors (in parentheses) are below coefficients and are clustered by firm. ***, **, * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Mechanism: Bottom Up Innovation I

- Look within Conventional Applications since 2003. Some calls were more "**non-specific**" (i.e. more like Open) than others

- Use Machine Learning NLP "text to data" algorithm to classify applications via words in proposal's abstract
  - e.g. "Happy" & "Joy" close; "Happy" & "Toolbox" are not
  - 300 dimensional vector space "embeddings"
  - Specifically, SpaCy pipeline in Python (trained on OntoNotes) with GloVe vectors trained on Common Crawl.

Mechanism: Bottom Up Innovation I

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  - e.g. "Happy" & "Joy" close; "Happy" & "Toolbox" are not
  - 300 dimensional vector space "embeddings"
  - Specifically, SpaCy pipeline in Python (trained on OntoNotes) with GloVe vectors trained on Common Crawl.

- For each competition calculate within-topic dispersion of the embeddings. Bigger dispersion = higher topic's non-specificity score

- *Validation:* average Open topic four times more non-specific than average Conventional topic (Table 1)

Table 7: Effect of Award on Patenting in Conventional Program by Topic Specificity

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) × 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

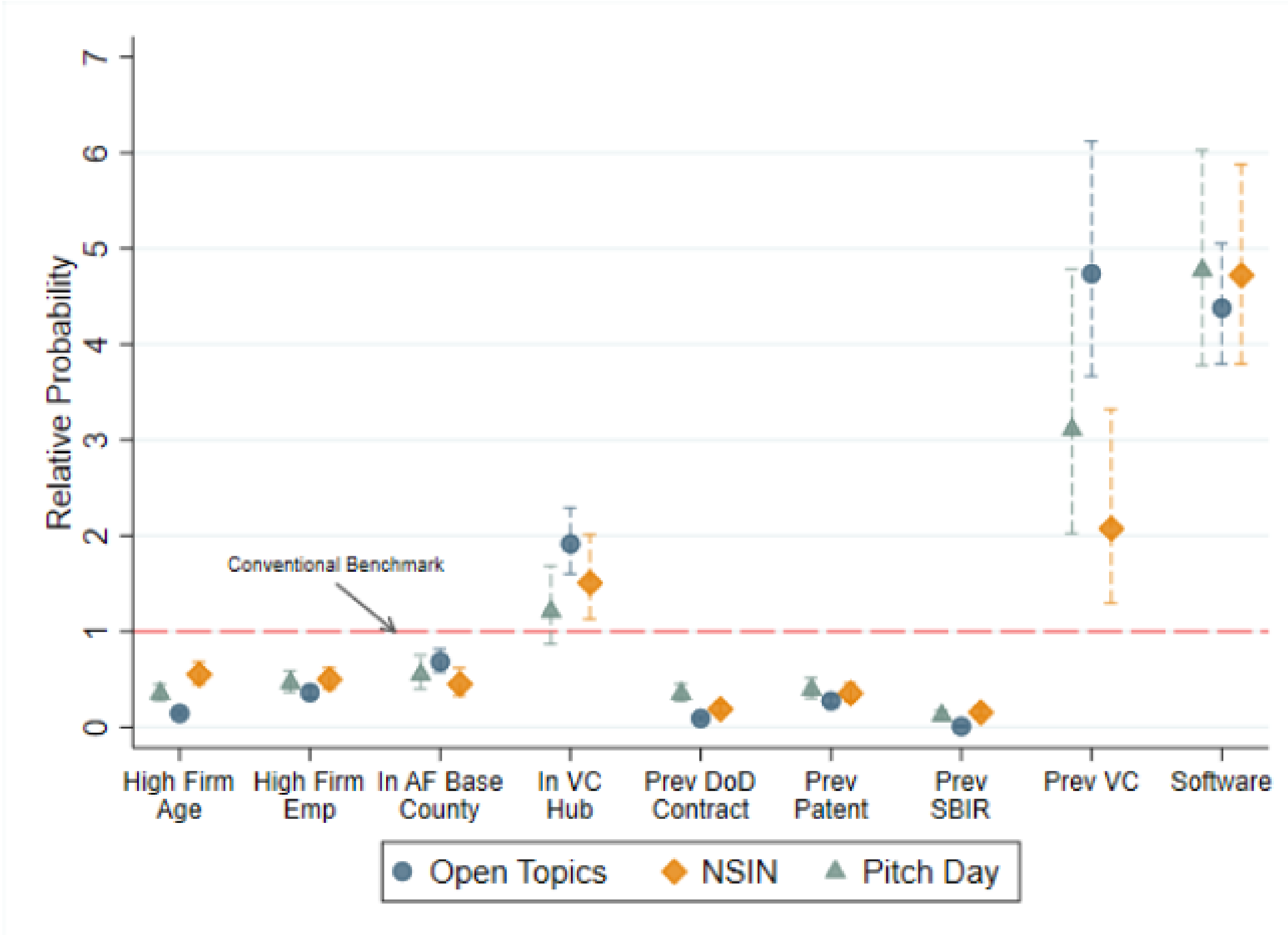
Note: This table shows regression discontinuity (RD) estimates of the effect of winning a Phase I award on patent-based variables within 24 months after the award decision in the Conventional program, where the effect of winning is modulated by the index of topic specificity. Specifically, we interact winning with our demeaned "non-specificity" index. A higher value of non-specificity means the topic is more bottom-up based on the diversity of proposals it attracted (see Section 6.3 for details). In Panel A, the dependent variable in columns (1) and (2) is an indicator for whether a firm was granted a patent that was applied for after the award decision. The other two outcomes are quality measures of these patents. Columns (3) and (4) consider whether a firm obtained a patent with above sample median future citations (defined among the applications in our sample). This is a measure of patent quality that is informative about the impact of a patent on future research. Columns (5) and (6) consider whether the patent had above median originality, which measures whether the patent cites previous patents in a wide range of fields. These outcomes are described in detail in Appendix C.2. In Panel B, we include the Open applications to assess whether there is still a robust interaction of award and Open after controlling for the effect of winning in non-specific Conventional topics. We do not include the citations outcome because there is not enough time after the Open awards for citations to accrue. The following statements apply to both panels: Rank within the topic (competition) is controlled separately as a linear function on either side of the cutoff. For each outcome, we report one model (odd columns) restricted to first-time applicants and one using all applications (even columns). All columns include topic fixed effects, which absorb the measure of specificity. We include all years (2003-19). Standard errors are under coefficients (in parentheses) and clustered by firm. ***, **, * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Mechanism: Bottom Up Innovation II

- Comparison to other reforms in 2018-19: **Pitch Day** and **NSIN**
  - ***Pitch Days*** held in VC hubs sought to link large procurement programs with startups. Senior officers from mission programs judges physically present & evaluate in usual way. But all on same day (Shark-Tank style)
  - ***National Security Innovation Network*** came from central DoD office, rather than one of the services. These topics share with Open topics a focus on dual-use viability

- Key feature is that both programs attracted new entrants by focusing on dual use like Open (see Fig 2)

Figure 2: Selection into Programs



Note: This figure shows how firm characteristics predict selecting into reform programs compared to the Conventional program. The points represent coefficients from a multinomial logistic regression with categories for four programs: the Conventional program, which serves as the base group and is represented by the red dashed line, and the three reform programs (Open, NSIN, and Pitch Day). Data restricted to 2017-2019. The dashed lines around each coefficient point indicate the 90% confidence intervals.

Mechanism: Bottom Up Innovation II

- But neither PitchDay nor NSIN were “bottom up” like Open.

- Hence, if Open treatment effect due to this decentralization & not just composition of new entrants
  - We should <u>not</u> observe the same large positive RDD treatments effects as Open.
  - We confirm this in Tab 6.

Table 6: Effect on Venture Capital Investment of Open, Conventional, and Other Reform Programs Relative to Each Other

Sample:	Open, Conv & NSIN	Open, Conv & Pitch Day	All	NSIN Topics	Pitch Day Topics
	(1)	(2)	(3)	(4)	(5)
$\mathbb{1}$(Award) × $\mathbb{1}$(Open Topics)	0.058**	0.058**	0.058**		
	(0.029)	(0.029)	(0.029)		
$\mathbb{1}$(Award) × $\mathbb{1}$(NSIN)	-0.015		-0.015		
	(0.060)		(0.060)		
$\mathbb{1}$(Award) × $\mathbb{1}$(Pitch Day)		-0.191***	-0.191***		
		(0.028)	(0.027)		
$\mathbb{1}$(Award)	-0.006	-0.006	-0.006	-0.022	-0.197**
	(0.020)	(0.020)	(0.020)	(0.064)	(0.022)
Observations	4416	4317	4740	423	324
Outcome Mean	0.045	0.044	0.047	0.076	0.065

Note: This table compares the effect of winning an award on the probability of any VC investment within 24 months after the award decision for Open, Conventional, and two other "reform" topics, relative to conventional topics. The other reform topics are Pitch Day and NSIN (discussed in the text). Rank within the topic (competition) is controlled separately as a linear function on either side of the cutoff. We fully interact all right-hand side variables with the coefficient of interest (e.g., rank on either side of the cutoff is interacted with the indicator for Open in column (1)). In columns (1) through (3), the base group is Conventional proposals. We assess whether the effect of winning Open and NSIN is significantly different from Conventional in column (1). Column (2) is similar, but considers Pitch Day instead of NSIN. Column (3) includes all four programs. In columns (4) and (5), we consider the effect of winning within Pitch Day and NSIN topics as separate samples, respectively. We use our main sample of first proposals from 2017-19 in all columns. Note the topic fixed effects control for the independent effects of Open, NSIN, and Pitch Day. Standard errors are clustered by topic in columns (1) through (3), and by firm in columns (4) and (5). ***, **, * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Outline

- Institutional background
- Data
- Econometric Strategy
- Results
- Mechanisms
- **Cost Benefit & Conclusions**

Cost-Benefit Analysis

- Consider USAF objective function:

Narrow **M**ilitary benefits

Non-Military benefits

Costs

$$V = \mu^M M(D, u^M) + \mu^N N(VC, u^N) - C$$

Welfare weight of military benefits

Unobserved military benefits

Welfare weight of non-military benefits

Unobserved non -military benefits

$ value of non-SBIR contracts

$value of VC funding

- **Marginal Decision:** For the next competition what is the net benefit (assume one winner, 5 losers)?

Cost-Benefit Analysis

- Use our estimated causal effects, average values $ values for VC and non-SBIR contracts and USAF estimated costs

- For baseline, we find **net benefit is $1 million for Open and ~$0 for Conventional (Table 8)**

Table 8: Cost-Benefit Analysis

All $ in thousands

A. Baseline Results

Program:	Open	Open	Conv	Conv
Outcome:	VC	Non-SBIR	VC	Non-SBIR
	(1)	(2)	(3)	(4)
1. Treatment Effect	0.052	0.075	-0.006	0.033
2. Average Contract Size	$11,085	$11,800	$11,805	$11,800
3. Implied Benefit	$576	$885	-$66	$389
4. Utility Weight	1	1	1	1
5. Benefit Sum	$1,461		$323	
6. Cost	$379		$333	
7. Net Benefit (Benefit - Cost)	$1,082		-$10	
8. Net Benefit Difference (Open - Conv)	$1,092			

Note: This table shows the cost benefit analysis using the regression discontinuity (RD) estimates of the treatment effect in Table 2. Panel A shows the baseline scenario, where we take the average VC and non-SBIR DoD contract size within 24 months after the award decision. The cost of the programs consist of the average Phase 1 and Phase 2 award amounts and the administrative cost of evaluating a winner. Panel B shows the various robustness scenarios, including using the pre-award contract sizes, considering solely the military (non-SBIR) benefit, assuming zero effects of winning a Conventional program on VC, expanding the analysis to all years (2003-19), and using different average contract sizes for Open and Conventional programs.

Cost-Benefit Analysis

- Use our estimated causal effects, average values $ values for VC and non-SBIR contracts and USAF estimated costs

- For baseline, we find **net benefit is $1 million for Open and ~$0 for Conventional (Table 8)**

- Extensions
  – Alternative assumptions (e.g. welfare weights)
  – Incorporate dynamics from lock-in
  – Allow military contract to reflect cost of development as well as value (model a la Bhattacharya, 2021)
  – **Open always has a positive benefit that exceeds Conventional**

- **Note:** Does not mean no role for Conventional, because there might be other benefits we are not measuring

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Outcome:	VC	Non-SBIR	VC	Non-SBIR
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B. Robustness

	Net Benefit Difference (1)	Open Net Benefit (2)	Conv Net Benefit (3)
1. Baseline	$1,092	$1,082	-$10
2. Pre-award Average Contract Sizes	$809	$783	-$26
3. Zero Weight on Non-Military	$449	$506	$56
4. Zero Coefficient on VC for Conv	$1,0426	$1,082	$56
5. Conv Coefficients from 2003-19	$1,246	$1,082	-$164
6. Separate Contract Size Averages for Open and Conv	$400	$465	$65

Note: This table shows the cost benefit analysis using the regression discontinuity (RD) estimates of the treatment effect in Table 2. Panel A shows the baseline scenario, where we take the average VC and non-SBIR DoD contract size within 24 months after the award decision. The cost of the programs consist of the average Phase 1 and Phase 2 award amounts and the administrative cost of evaluating a winner. Panel B shows the various robustness scenarios, including using the pre-award contract sizes, considering solely the military (non-SBIR) benefit, assuming zero effects of winning a Conventional program on VC, expanding the analysis to all years (2003-19), and using different average contract sizes for Open and Conventional programs.

Conclusions

- US military R&D key exhibit for supporters of mission driven, innovation based industrial policy.
  - But faltering innovation in this hugely important sector
  - We present first causal evaluation of defense R&D program
- Trade-offs in between decentralized (bottom-up) and centralized (top-down) innovation strategies
- Open reforms seem to benefit DoD & private economy
  - **Selection**: Reduces lock-in advantages for incumbents & attracts more diverse new entrants
  - **Openness:** Seems to play an additional role

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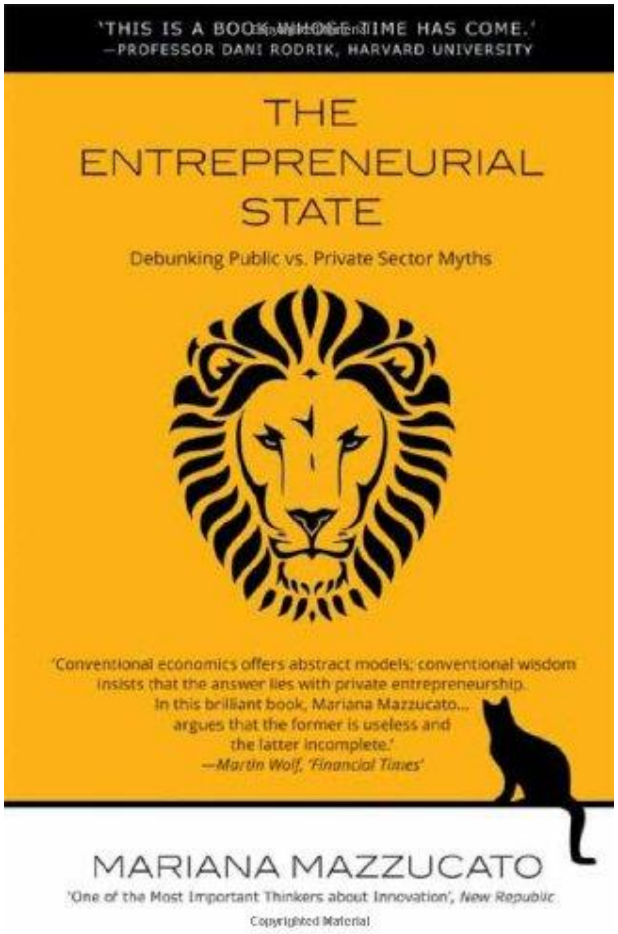
- Open reforms seem to benefit DoD & private economy
  - **Selection**: Reduces lock-in advantages for incumbents & attracts more diverse new entrants
  - **Openness:** Seems to play an additional role
- Relevant beyond defense:
  - Firms increasingly using bottom-up approaches through customer-driven, outsourced, or open innovation Chesbrough (2003), de Villemeur and Versaevel (2019)
- Innovation funders could benefit from more bottom-up, decentralized approaches

Back Up

From US DARPA to UK ARIA



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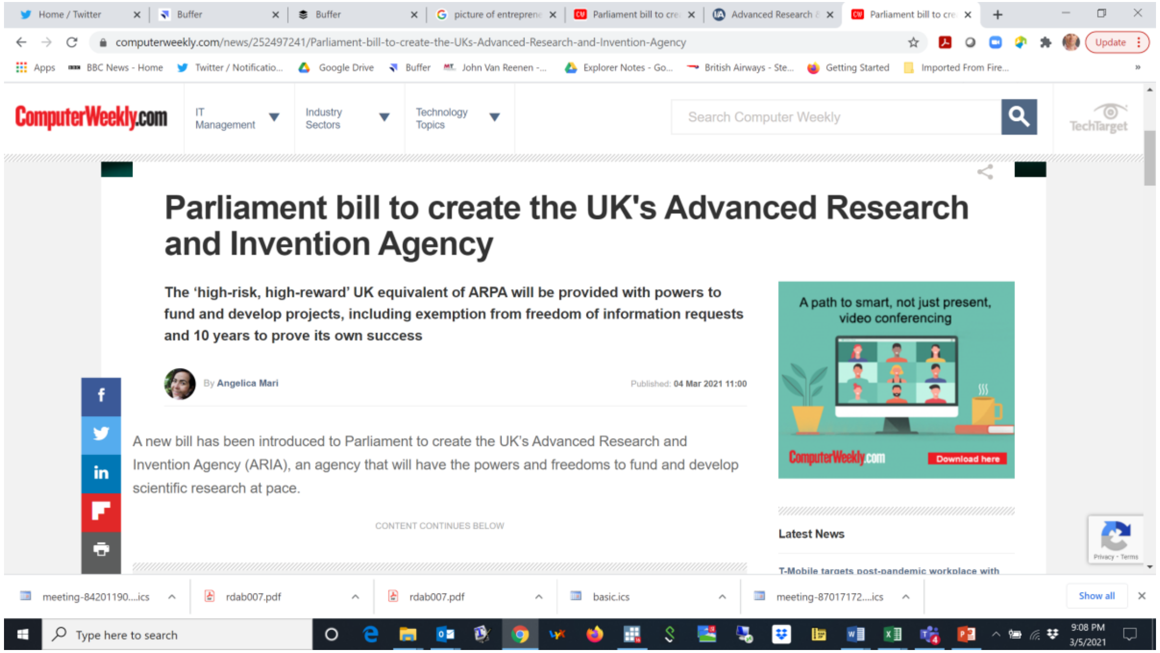
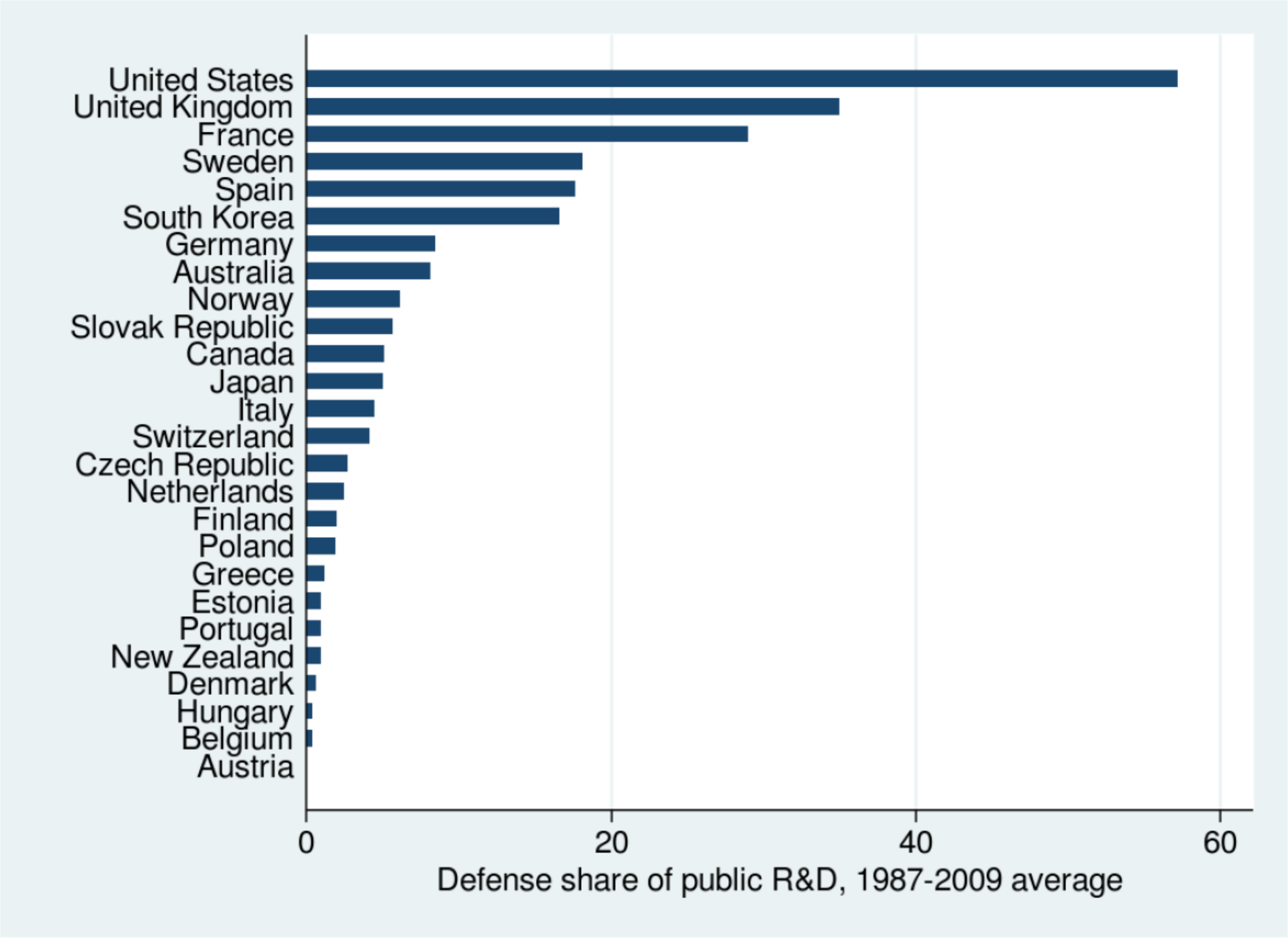
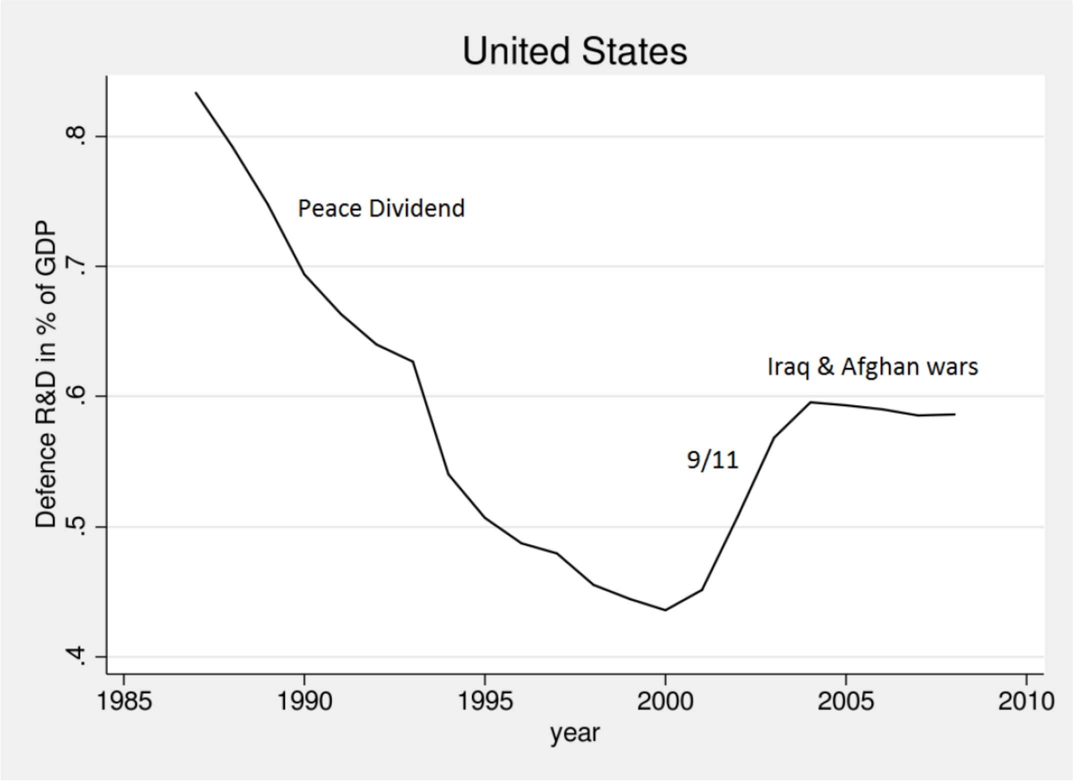


Defense share of public R&D

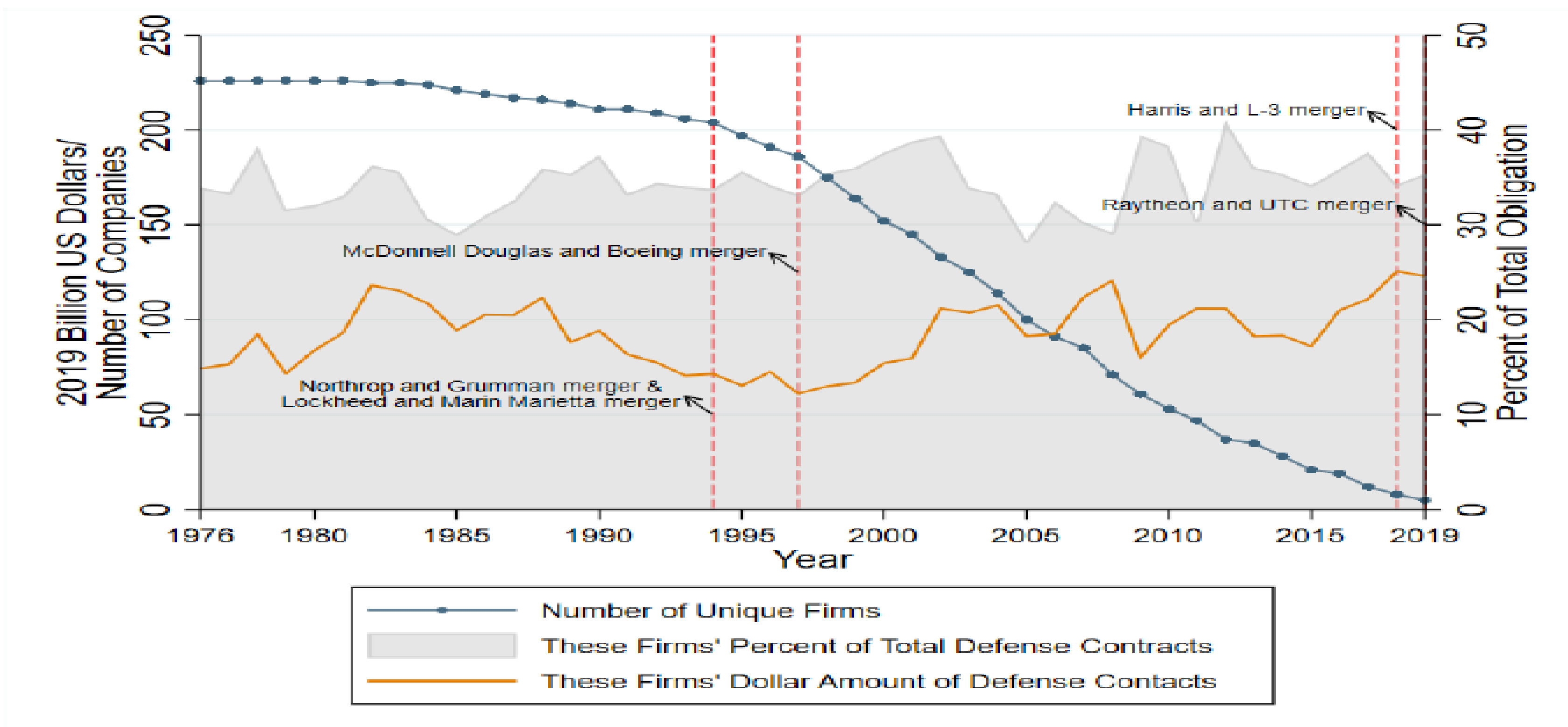


Defense R&D as share of GDP, US



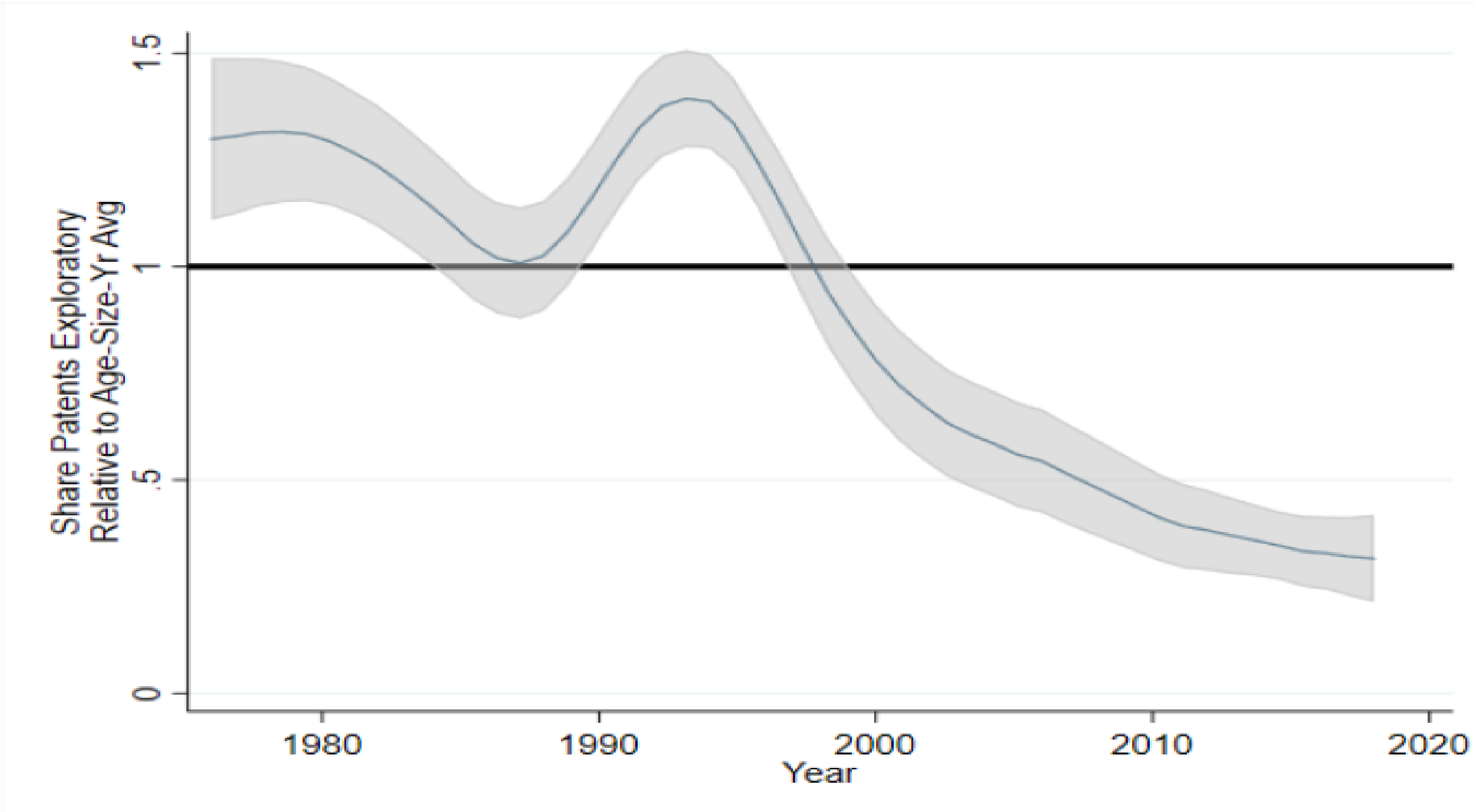
Is part of this due to increased concentration? Big increase in dominance of a few firms

Figure A.1: Consolidation of Prime Defense Contractors



Note: This figure shows the trend of defense contractors' consolidation since the 1980s. We first define prime defense contractors as the top contractors between 2000 and 2020: Boeing, Raytheon, Lockheed Martin, Northrop Grumman, General Dynamics, United Technologies Corp, Harris, and L-3. We then identify all their acquisitions of other defense contractors starting in 1976. The blue line shows the number of unique firms in each year, from 226 in 1976 to just six in 2020. The gray area shows the share of all DoD contracts (in nominal dollars) that are awarded to the top eight prime defense contractors and their acquisition targets. The total value of these contracts (in 2019 dollars) is shown in the orange line. For example, the 226 firms accounted for about \$70 billion or 33% of the total defense contract value, in 1976. They consolidated to six companies by 2019, at which point those six accounted for \$115 billion, or 35% of the total defense contract value. Data are sourced from the Federal Procurement Data System (FPDS) and Defense Contract Action Data System (DCADS).

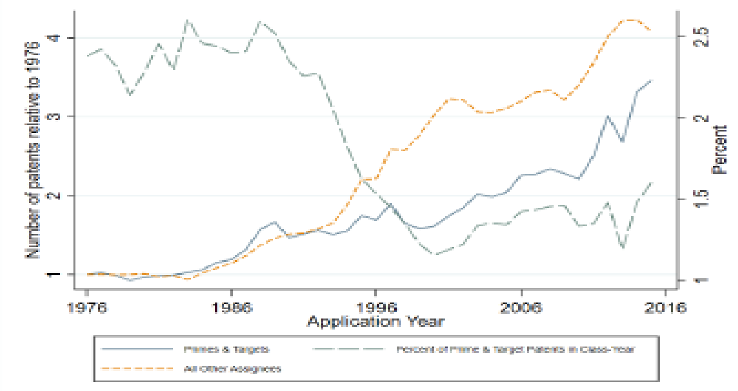
Figure A.2: Exploratory Patents from Prime Defense Contractors



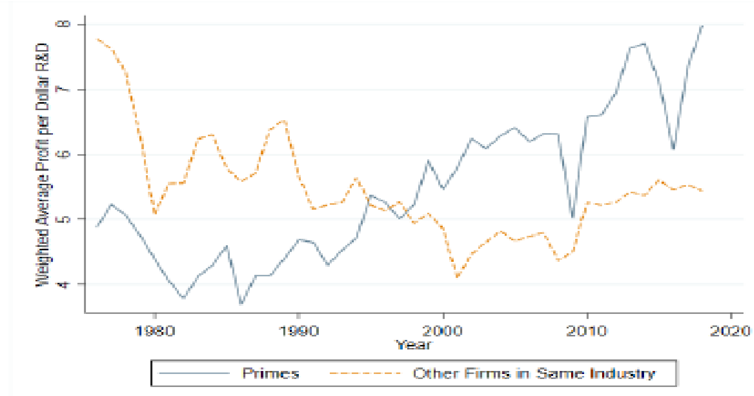
Note: This figure describes the trend of exploratory innovation by the prime defense contractors and their acquisition targets over time. The firms are the same set from Figure A.1. That is, 226 firms are included in 1976, while only six are included in 2019 (as the 226 have merged into these six). The graph shows these firms' average share of exploratory patents relative to other firms with similar in age, size, and year. An exploratory patent is a patent filed in a technology class previously unknown to the firm in a given year. Age is defined as the year from the firm's first observed patent and size is defined as the firm's patent stock in a given year. The measures in both figures are smoothed using kernel-weighted polynomial regressions. The gray band around the relative citations represents the 95% CI. Data are sourced from the USPTO.

Figure A.3: Historical Dynamics of Prime Defense Contractors

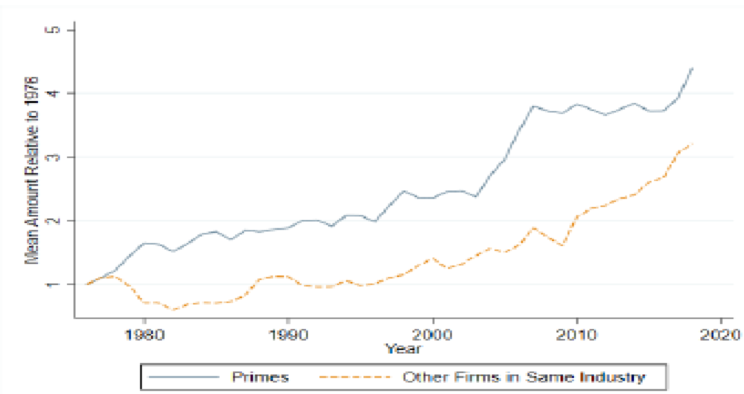
(a) Number of Patents



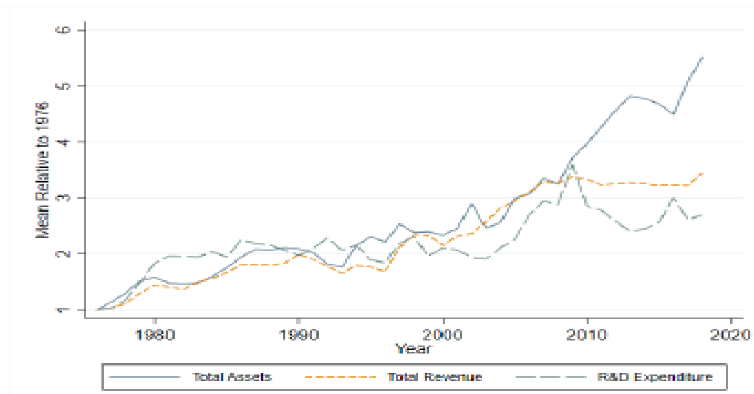
(b) Profit per Dollar R&D



(c) Profits



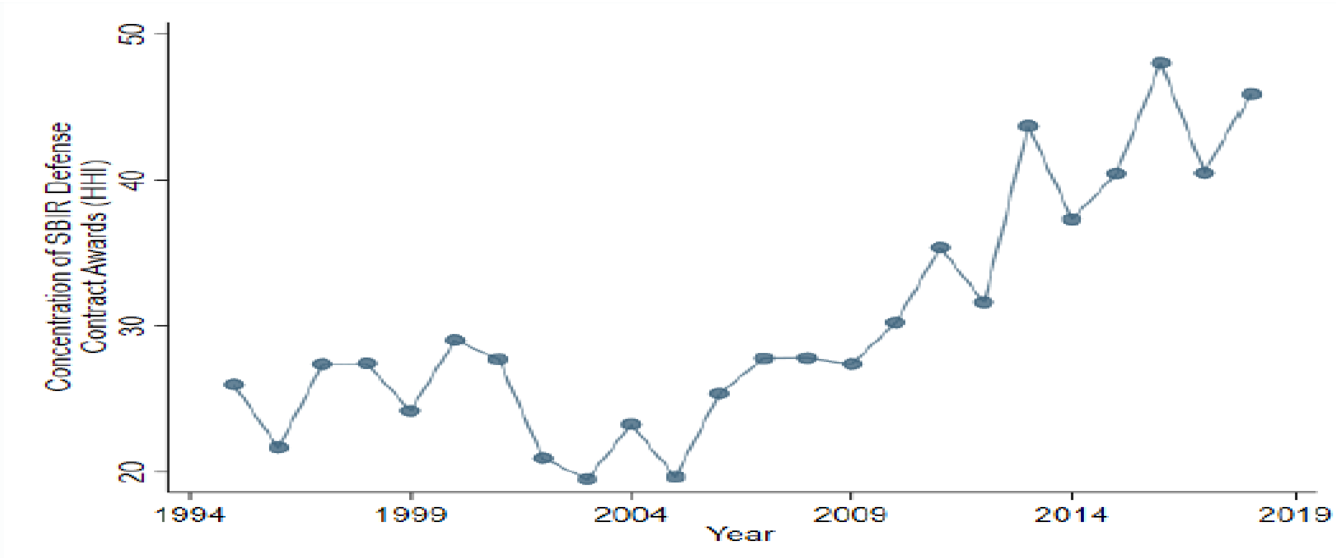
(d) Total Assets, Revenue, and R&D Expenditure



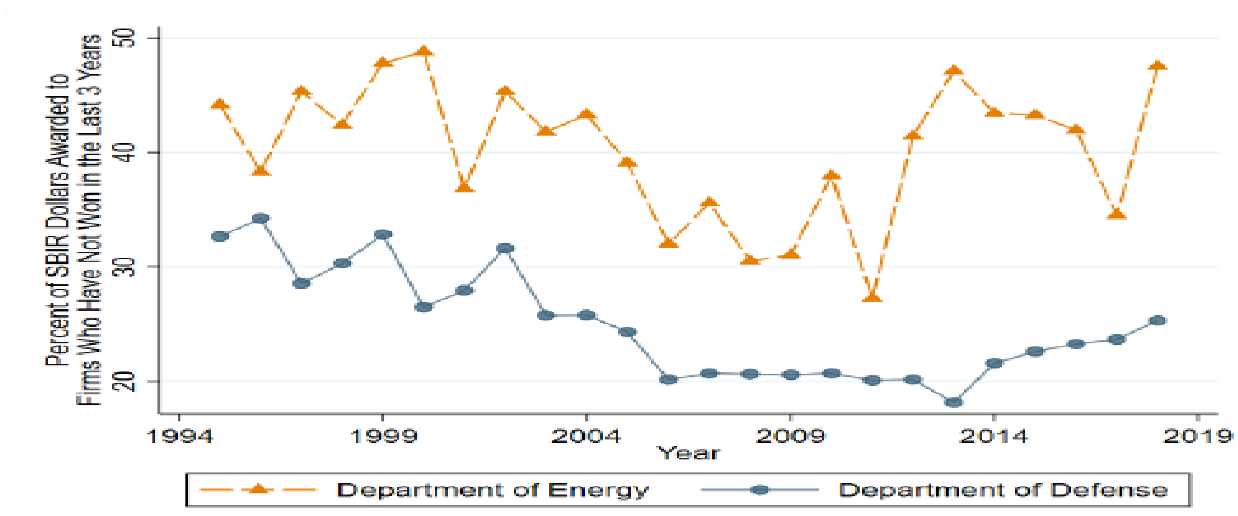
Note: This figure shows the dynamics of prime defense contractors. Panel A shows growth in the number of granted patents for prime defense contractors and their acquisition targets (blue line) and the number of granted patents for all other assignees (orange line) from 1976 - 2016, using data from the U.S.PTO. The teal line shows the share of prime defense contractors and their acquisition targets' patents in their class-year. The number of patents is scaled by 1976 levels (1976=1). We exclude 2016–on because there is a 2-3 year time period between application and patent award, so there are far fewer granted patents in the most recent application years. Panel B shows the weighted average profit per dollar of R&D for prime defense contractors compared to other Compustat firms in the same 3-digit SIC code (334 and 336). Panel C shows the growth of profits for prime defense contractors compared to other Compustat firms in the same 3-digit SIC code (334 and 336) relative to 1976 (1976=1) from 1976 to 2019. Panel D shows the growth of total assets, total revenue, and R&D expenditures in constant 2019 U.S. dollars for prime defense contractors, scaled by the 1976 level. Panel A includes the prime defense contractors and their acquisition targets; Panels B, C, and D only include the prime defense contractors and not their acquisition targets.

Figure A.4: 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



Note: Panel A in this figure shows the Herfindahl–Hirschman Index (0-10,000) for Non-SBIR Department of Defense contracts from 1990 to 2018. Panel B shows the share of "new" firms winning awards from the SBIR programs at the Department of Defense (DoD) and the Department of Energy (DoE). Each line plots the percentage of SBIR contract dollars awarded to firms that have not won a contract in the last three years. At the beginning of the sample in the early 1990s, the share of SBIR awards to firms that have not won in the last three years are relatively similar at the two agencies, but the series subsequently diverge. Data from DCADS, FPDS, and the U.S. Small Business Administration.

Table 1: Summary Statistics for Main Estimation Sample

Panel A: Competition and Company Summary

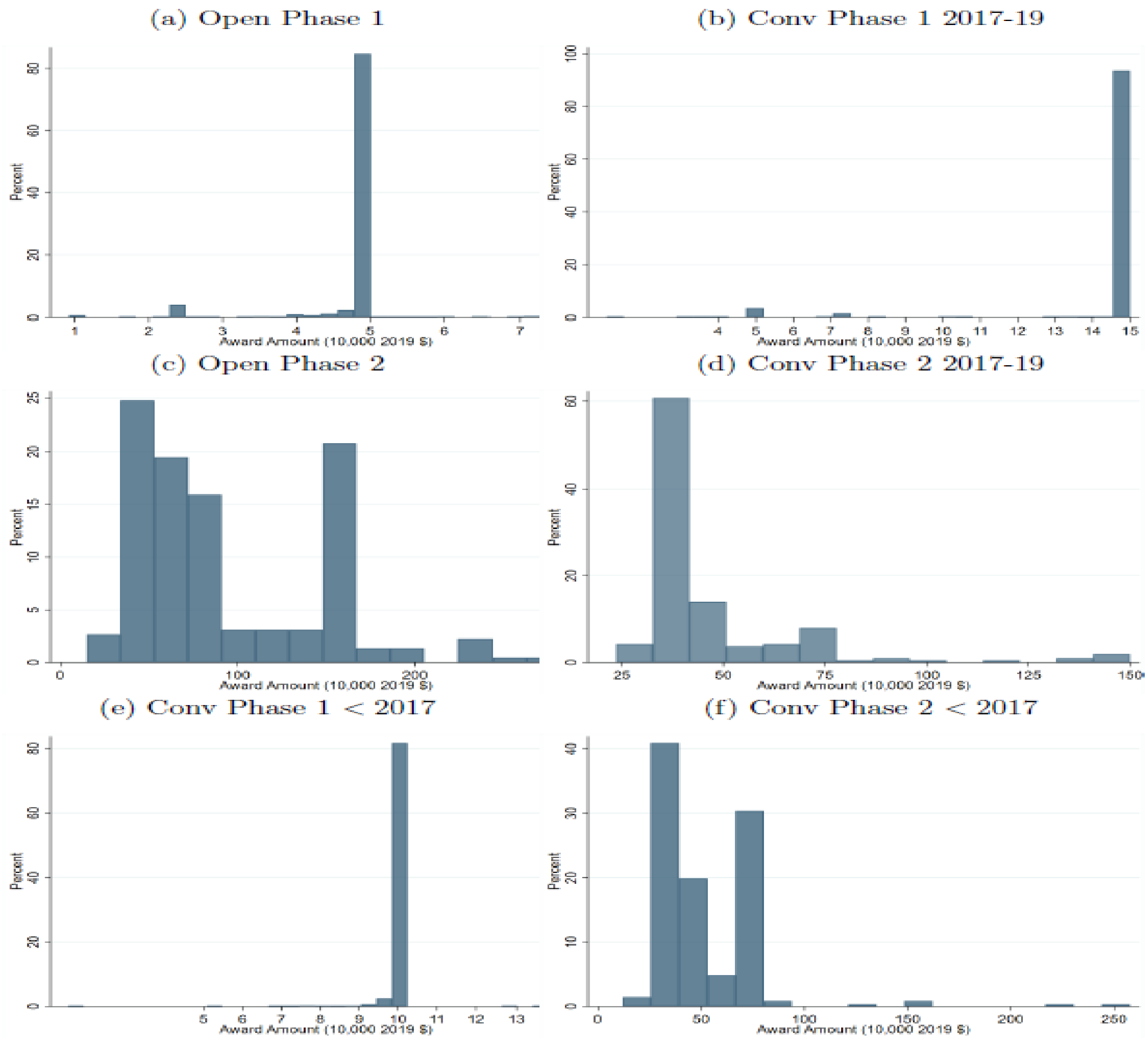
	Open Topic				Conventional			
	N	Mean	Median	SD	N	Mean	Median	SD
Competition Summary								
Num Proposals per Topic	1,659	379.327	375	156.453	4,995	19.808	15	17.131
Num Winners per Topic	1,659	212.842	297	115.083	4,995	3.090	2	3.606
Topic Non-Specificity	1,648	3.907	4	0.515	4,974	1.000	1	0.540
Award 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
$\mathbb{1}$(in VC Hub)	1,659	0.197		0.397	4,995	0.148		0.355
$\mathbb{1}$(in County with AF Base)	1,659	0.192		0.394	4,995	0.275		0.446
$\mathbb{1}$(Minority Owned)	1,659	0.121		0.326	4,993	0.127		0.333
$\mathbb{1}$(Woman owned)	1,659	0.111		0.314	4,993	0.155		0.362
$\mathbb{1}$(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
$\mathbb{1}$(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
$\mathbb{1}$(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
$\mathbb{1}$(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
$\mathbb{1}$(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
$\mathbb{1}$(Never Awarded SBIR)	1,659	0.691		0.462	4,995	0.283		0.451

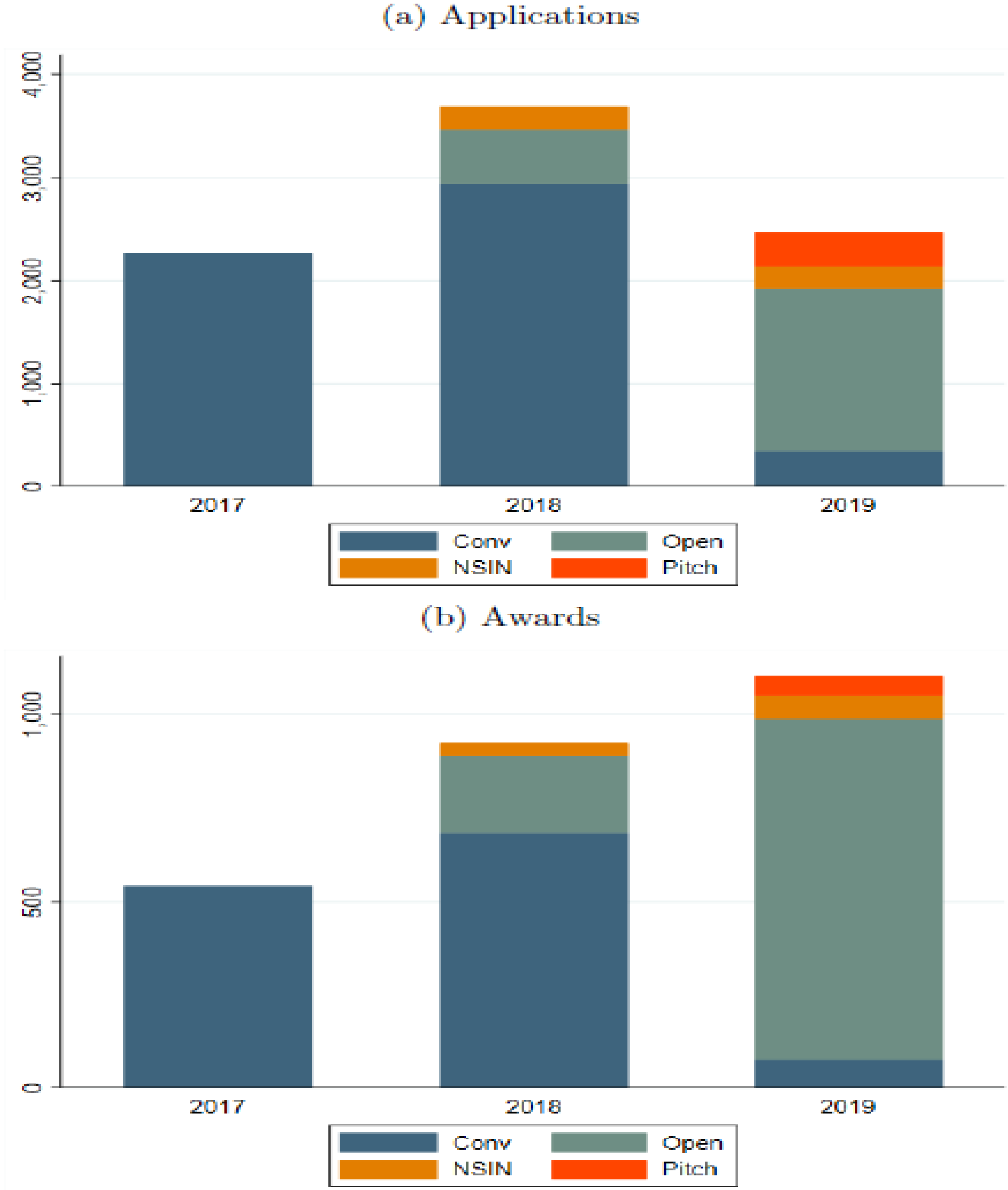
Note: Panel A of this table shows summary statistics about the Phase 1 competitions, as well as select company characteristics as of the application date. Panel B shows summary statistics of variables used as outcomes in the analysis, all calculated for the period before the award decision to facilitate evaluating selection into applying for the different programs. The data are restricted to all applications in our main analysis sample (the Open and Conventional programs from 2017-19).

Figure A.5: Histograms of Award Amounts by Topic Type and Phase



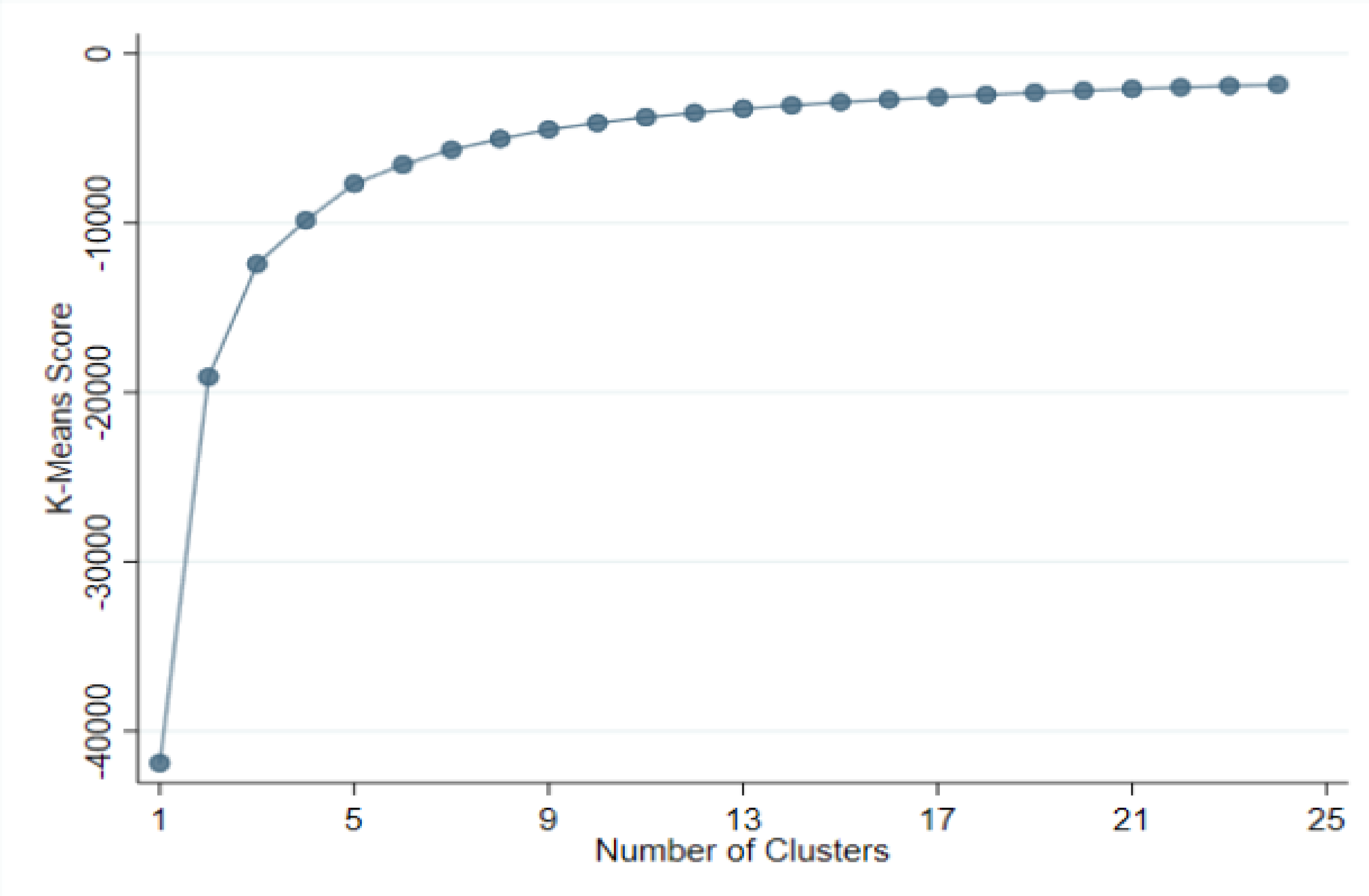
Note: These histograms show the share of awards by amount, in real 2019 dollars. For the bottom right graph (Phase 2 <2017), we omit one outlier $12 mill contract.

Figure A.6: Number of Applications and Awards Over Time by Topic Type (Analysis Sample)



Note: These figures show the number of applications (top) and awards (bottom) in our "analysis sample" of data from 2017-2019 by topic type.

Figure A.7: K-means Optimal Number of Clusters (Elbow Method)



Note: This figure shows the k-means score for 1-25 clusters. The k-means score is defined as the negative total squared error between the cluster members and their centroid. The optimal number of clusters, or the "elbow," is identified for the number of clusters k for which the objective improves significantly and plateaus thereafter. We identify the optimal cluster to be $k = 5$.

Figure A.8: Keywords for K-means 2 Cluster Model Scaled by Importance to Topic

(a) Hardware

(b) Training/Software

Note: These figures show the keywords that are identified as a topic cluster by the k-means cluster algorithm, where the algorithm has been assigned to find two clusters. The word's size reflects its prevalence in the topic.

Figure A.9: Keywords for K-means 5 Cluster Model Scaled by Importance to Topic

(a) Software/Security

(b) Materials/Manufacturing

(c) Simulation/Engineering

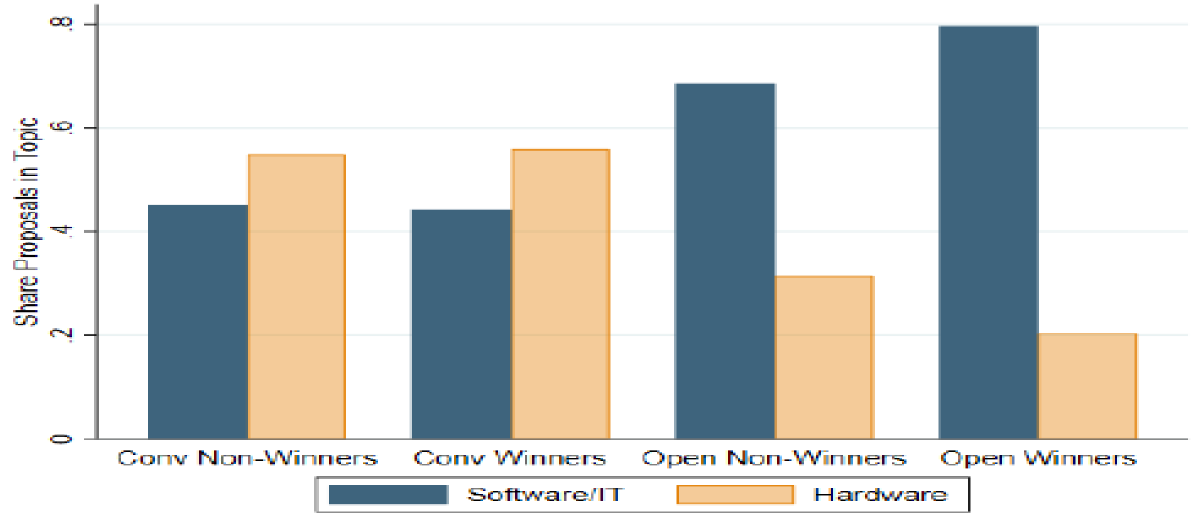
(d) Sensor/Data

(e) Optical/Measurement

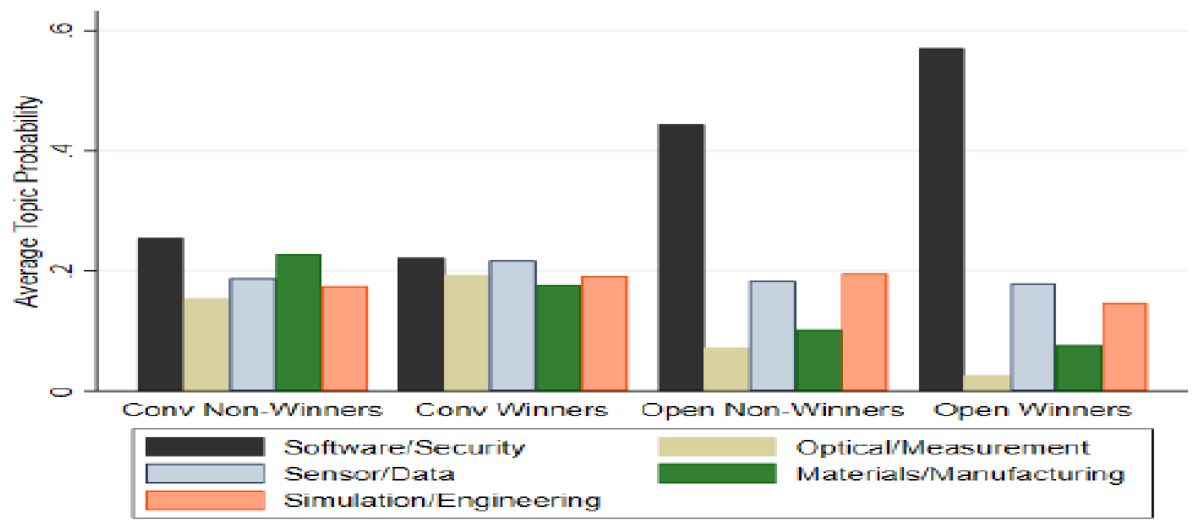
Note: These figures show the keywords that are identified as a topic cluster by the k-means cluster algorithm, where the algorithm has been assigned to find five clusters. Five is the optimal number of clusters according to the elbow method (see Figure A.7). The word's size reflects its prevalence in the topic.

Figure A.10: Applicant Technologies (Based on K-means Clustering of Abstract Text)

(a) Model with Two Clusters



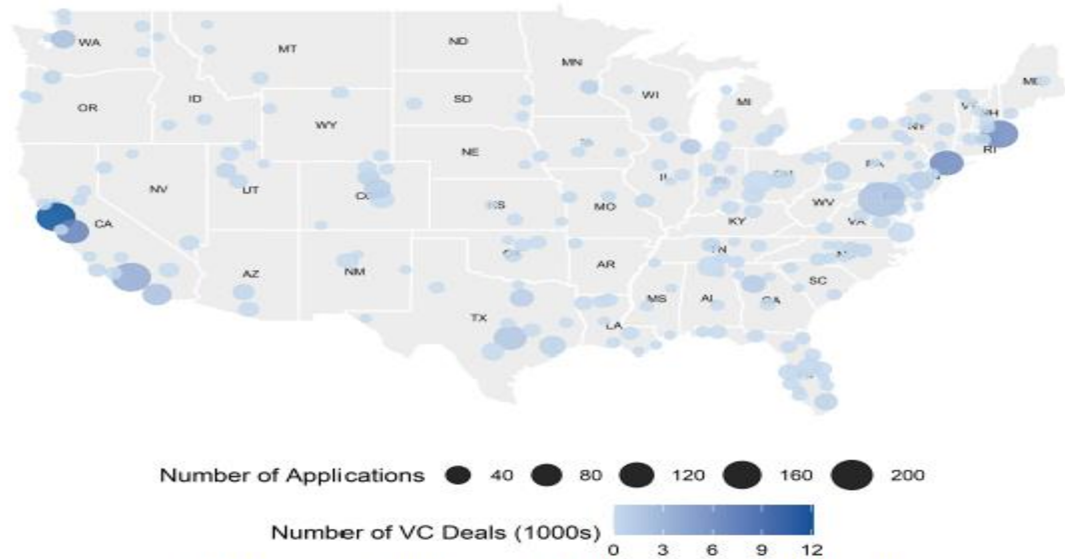
(b) Model with Five Clusters



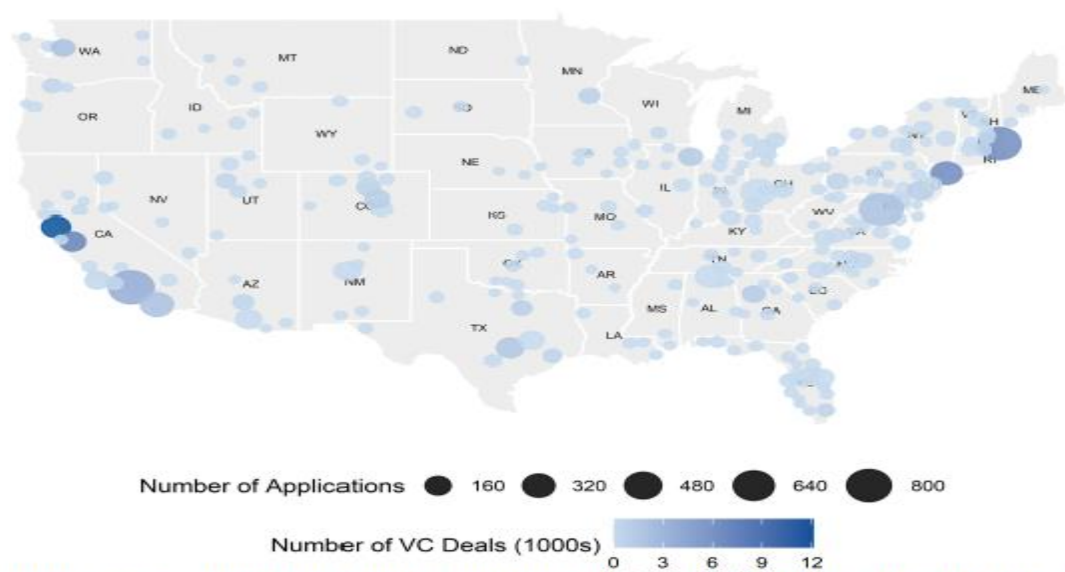
Note: These figures show the distribution of applications by topic based on a k-means cluster model, described in Section 3.2. Panel (a) shows the model pre-set to produce two clusters. Panel (b) shows the model with the optimal number of clusters, which is the one for five clusters. In each case, all applications are assigned to exactly one cluster. In each panel, we divide the sample into four groups by program type (Conventional and Open) and winner status. We then show the percent of applications within each group by topic type.

Figure A.12: Geographic Dispersion of Applications (2017-19)

(a) Open Topic Applications and VC Deals



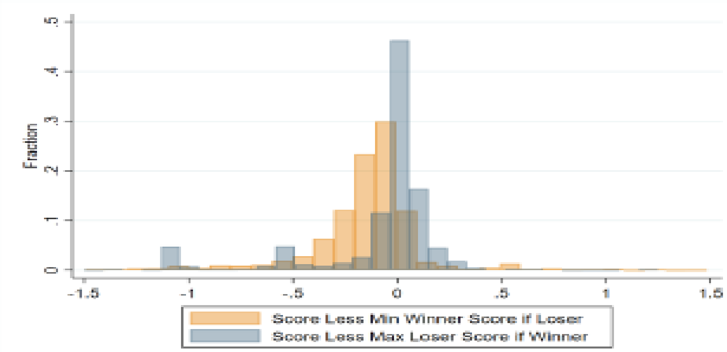
(b) Conventional Topic Applications and VC Deals



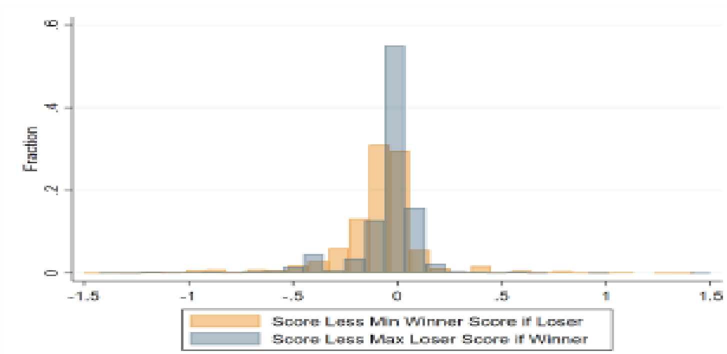
Note: These maps show the number of applications to open (Panel A) and conventional SBIR topics (Panel B) by MSA from 2017 to 2019. The size of the bubble represents the relative number of applications. The color gradient in both maps also show VC activity by MSA.

Figure A.18: Prevalence of Crossover Sub-scores

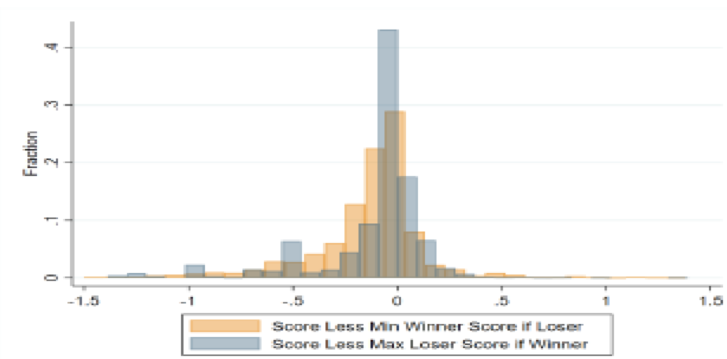
(a) Tech Score



(b) Team Score



(c) Commercialization Score



Note: These histograms demonstrate the substantial variation in the three sub-scores (tech, team, commercialization) around the cutoff. The red bars to the right side of zero show that many unsuccessful applicants (losers) have a sub-score that exceeds the lowest sub-score among winners. Similarly, the blue bars to the left side of zero show that many winners have sub-scores that are lower than the highest loser sub-score. Altogether, 81% of applicants have at least one sub-score that is a "crossover." All topics 2017-19 are included.

The non-specific index can account for Open's advantage

Panel B: The Role of Topic Specificity in Conventional and Open Topics

	Any Patent		Any High Originality Patent	
	(1)	(2)	(3)	(4)
$\mathbb{1}$(Award)	-0.011	0.001	-0.029	-0.008
	(0.028)	(0.016)	(0.023)	(0.015)
$\mathbb{1}$(Award) × $\mathbb{1}$(Open)	-0.059	-0.056	-0.029	-0.011
	(0.081)	(0.053)	(0.069)	(0.044)
$\mathbb{1}$(Award) × Non-specificity	0.047*	0.039**	0.037*	0.021
	(0.027)	(0.016)	(0.022)	(0.014)
Observations	8073	18463	8073	18463
Proposals	First	All	First	All
Outcome Mean	0.138	0.224	0.091	0.157

Note: This table shows regression discontinuity (RD) estimates of the effect of winning a Phase 1 award on patent-based variables within 24 months after the award decision in the Conventional program, where the effect of winning is modulated by the index of topic specificity. Specifically, we interact winning with our demeaned "non-specificity" index. A higher value of non-specificity means the topic is more bottom-up based on the diversity of proposals it attracted (see Section 6.3 for details). In Panel A, the dependent variable in columns (1) and (2) is an indicator for whether a firm was granted a patent that was applied for after the award decision. The other two outcomes are quality measures of these patents. Columns (3) and (4) consider whether a firm obtained a patent with above sample median future citations (defined among the applications in our sample). This is a measure of patent quality that is informative about the impact of a patent on future research. Columns (5) and (6) consider whether the patent had above median originality, which measures whether the patent cites previous patents in a wide range of fields. These outcomes are described in detail in Appendix C.2. In Panel B, we include the Open applications to assess whether there is still a robust interaction of award and Open after controlling for the effect of winning in non-specific Conventional topics. We do not include the citations outcome because there is not enough time after the Open awards for citations to accrue. The following statements apply to both panels: Rank within the topic (competition) is controlled separately as a linear function on either side of the cutoff. For each outcome, we report one model (odd columns) restricted to first-time applicants and one using all applications (even columns). All columns include topic fixed effects, which absorb the measure of specificity. We include all years (2003-19). Standard errors are under coefficients (in parentheses) and clustered by firm. ***, **, * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Table A.1: Proposal and Firm 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

Table A.2: Summary Statistics for Other Reform Programs and Full Conventional Time Period

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

Note: This table repeats the summary statistics from Table 1 but for two different data sets. First, on the left side of each panel, is data from the whole Conventional sample spanning 2003-19. Second, on the right side of each panel, is data from the other DoD SBIR reform programs that we consider in Section 6.2.

Table A.3: 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

Note: This table repeats the summary statistics from Table 1 Panel A but for the Phase 2 competitions from 2017-19.

Table A.5: Effect of Winning on Any Patenting Outcomes (originality and generality defined within AF SBIR applicants in year)

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

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

Note: This table shows effects of winning an award on alternative patent-based metrics. Panel A shows regression discontinuity (RD) estimates of the effect of winning a Phase 1 award on any subsequent granted high originality patent within 24 months after the award decision, for Open and Conventional topics. The originality score measures whether the patent cites previous patents in a wide range of fields. We define a patent to be highly original if its originality score is above the median in the sample of all applicant patents. Rank within the topic (competition) is controlled separately as a linear function on either side of the cutoff. Panel B shows regression discontinuity (RD) estimates of the effect of winning a Phase 1 award on any subsequent granted high citation and generality patent within 24 months after the award decision for Conventional topics. These measures are based on citations that accrue after a patent is granted and there is not enough time to observe them for the more recent Open program. Columns 1 and 3 include years 2017-19 and columns 2 and 4 include all years 2003-19. The sample is restricted to first-time applicants only, except in Panel A column 6. In all cases, we control for previous Air Force SBIR awards. All columns in both panels include topic fixed effects. Standard errors are clustered by firm in panel A columns (1)–(3). Standard errors are clustered by topic in columns (4)–(6) in panel A and all columns in panel B. ***, **, * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Table A.6: Phase 2 VC and Government Matching (Open Topics Only) 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

Note: This table contains summary statistics about the private and government matching among Open Phase 2 awardees.

Table A.7: 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)
1(Award)	0.040*	0.015	-0.047	0.074	0.026
	(0.025)	(0.013)	(0.042)	(0.062)	(0.049)
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

Note: This table contains regressions showing the effect of winning a Phase 1 award on measures of VC within 24 months of the award decision interacted with indicators for private and government matching (only available to Open Phase 2 awardees) on subsequent venture capital. In column 1, the dependent variable is redefined to be zero for firms that got a VC match. That is, the dependent variable is zero if a firm got VC and also got a VC match. In column 2, we consider the complement. The dependent variable is redefined to be zero for firms that got VC but had no VC match. That is, the dependent variable is only equal to one for firms that got VC and a VC match and is zero otherwise. Column 3 includes only those topics that offered a match, (19.1, 19.2, and 19.3), while column 4 includes the remaining topics that did not offer a match (18.2 and 18.3). Column 5 shows the interaction. All models include topic fixed effects. The sample is restricted to first-time applicants only. Standard errors are clustered by firm. ***, **, * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Description:

OBJECTIVE: The purpose of this effort is to develop safe, large-format Li-ion batteries where effects of cell and battery failure is minimized.

DESCRIPTION: Rechargeable Li-ion batteries can fail violently when subjected to an internal electrical short, are overheated, crushed, or when they are overcharged/overdischarged. Recent events such as the grounding of a commercial aircraft due to Li-ion battery fires demonstrate that the safety of Li-io is of major concern. Hazards are amplified by batteries and personnel operating together in confined spaces. Of particular interest are improvements in s large-format Li-ion batteries by eliminating cell-to-cell thermal transport and cell failure propagation. Safe containment of flames and debris during any thermal runaway event is paramount to the usefulness of the battery. Containment would prevent damage to surrounding equipment and personnel ou battery case. Interest would be given to solutions that are resistant to long storage and operation in high humidity, salt fog, and occasional fine sand env These new batteries will demonstrate improved safety under various abuse/extreme conditions while providing low impedance electrical performance. I in this topic should place an emphasis on reducing the acquisition cost to levels competitive with existing Li-ion, lead-acid, Lithium Thermal and nickel-c military batteries in terms of acquisition and life cycle. During Phase II, the offeror will produce a prototype battery that is compatible electrically and me to a chosen Air Force (AF)/ICBM modular application at both the Launch Facility and Launch Control Center Battery. The prototype will provide superior both by dimensions and weight when compared to current battery. The offeror will also compare the performance to the baseline battery system. The Ph prototype should be delivered to the AF for additional testing and evaluation. At the end of the contract, the offeror should also demonstrate the prototy outbrief technology advancements.

PHASE I: Develop an innovative, safe, large-format rechargeable Li-ion battery that does not have cell-to-cell propagation of a cell failure. Li-ion batteries equivalent/better energy/power density capability relative to current high rate Lead-Acid technology. Present experimental and other data to demonstra feasibility of proposed solution. Develop initial transition plan.

PHASE II: Produce alternative, safer Li-ion battery using the developed configuration for AF/ICBM on-demand power application. The prototype battery/r size will be determined during Phase I and during Phase II will be electrically and mechanically compatible to the target application. Provide cost project substantiating the design, performance, operational range, acquisition, and life cycle cost. Refine transition plan and business case analysis.

PHASE III: Commercial applications include hybrid and electric vehicles. Demonstrate volume manufacturability of the design. The military applications aircraft emergency and pulse power, electric tracked vehicles, unmanned systems, hybrid military vehicles, and unmanned underwater vehicles (UUVs).

REFERENCES:

1: Kim, G.H., Smith, K., Ireland, J., and Pesaran, A., "Fail-safe design for large capacity lithium-ion battery systems," J. Power Sources, Vol. 210 (2012) pp. 2

2: Eliud Cabrera-Castilloa, Florian Niedermeiera, Andreas Jossenb, " Calculation of the state of safety (SOS) for lithium ion batteries", J. Power Sources, V (2016) pp. 509-520

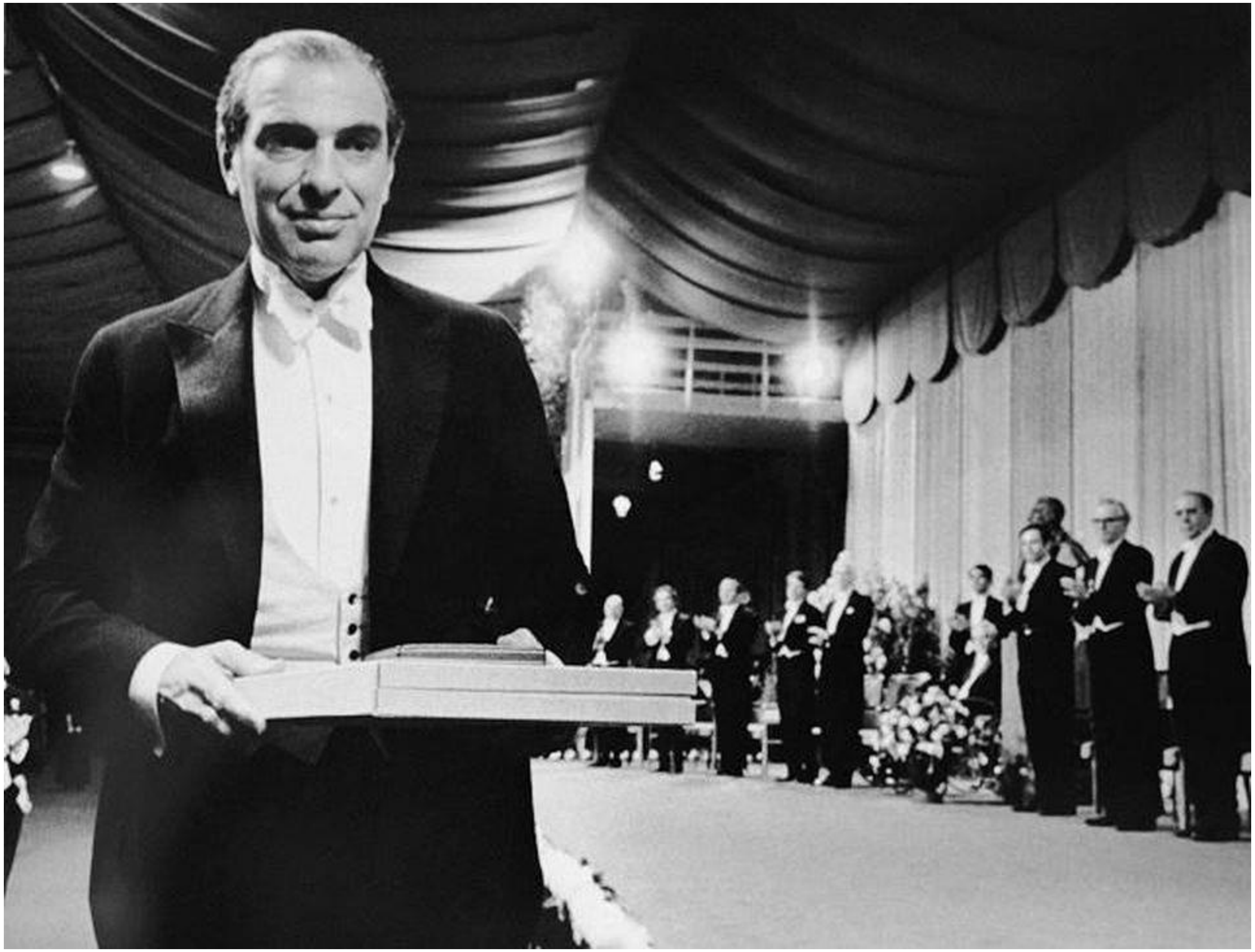
Mission Oriented Innovation:

The example of Military R&D

Vector Embeddings, Non-Specificity & Clusters

- Use text of abstract of proposal. Each word is mapped to vector space of conceptually similar words (using pre-trained model based on corpuses)
  - "Happy" & "Joy" close; "Happy" and "Toolbox" are not
- Specifically, SpaCy pipeline in Python (trained on OntoNotes) with GloVe (Global Vectors for Word Representation) vectors trained on Common Crawl.
- Each vector [how many?] consists of 300 elements on a {-1,+1} support. We average across to get a single 300x1 vector. We then reduce to 2x1 using isometric mapping
- Using all the 2x1 vectors of applications in a topic we use squared Euclidean distance to the average (centroid). Greater average distance means more non-specific
- Also using the embeddings use kmeans clustering (k-means clustering (Forgy, 1965; Bonhomme & Manresa, 2015) to get software/hardware distinction

An ex USAF mathematical economist



https://www.forbes.com/sites/forbesleadershipforum/2017/02/24/how-kenneth-arrow-revolutionized-our-understanding-of-elections-and-other-big-decisions-we-make/?sh=5383ed9c3cf3

Examples for Non-Specificity Measure

- Top 1% of non-specificity (i.e. **least** specific)
  - *"Wearable Device to Characterize Chemical Hazards for Total Exposure Health" (https://www.sbir.gov/sbirsearch/detail/1486629)*
  - *"Extended Weather Measurements in Support of Remotely Piloted Aircraft" (https://www.sbir.gov/node/1482495)*

- Bottom 1% of non-specificity (i.e. **most** specific)
  - *"Landing Gear Fatigue Model K Modification" (https://www.sbir.gov/sbirsearch/detail/1514289)*
  - *"Mitigation of Scintillation and Speckle for Tracking Moving Targets" (https://www.sbir.gov/node/870209)*