Open Innovation in the US Air Force

by
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Submitted to the Institute for Data, Systems, and Society and the Department of Electrical Engineering & Computer Science in partial fulfillment of the requirements for the degrees
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Abstract

If the Air Force is to maintain lethality and readiness, we must learn to adapt technologies and praxis within an increasingly diffuse knowledge landscape. This thesis examines two efforts orchestrated through AFWERX that seek to invigorate grassroots problem-solving and reform research and development partnerships with small businesses.

Stepping back, chapter one motivates and characterizes the ideological shift within the Department of Defense (DoD) towards *agility*, highlighting pioneering efforts and their challenges. Chapter two turns to the Squadron Innovation Fund (SIF), introduced in 2018 to empower mission-oriented units to address capability and efficiency gaps. The chapter contributes a data-driven perspective on the spending trends, draws lessons from analogous efforts in industry, and offers practical steps to leverage the potential of the SIF as a bottom-up signal for heavier funding sources. Chapter three evaluates the state of the Small Business Innovation Research (SBIR) program and traces its rapid reform under AFWERX, thereby setting up a rigorous econometric evaluation of these reforms in chapter four.

Together, these chapters chart out a way forward for the SIF while providing evidence that AFWERX's modifications to SBIR are drawing a more desirable applicant pool.

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Chapter 1

Introduction

1.1 Overview

The Department of Defense (DoD) is missing out on technological innovation. In response, the DoD is reconsidering its posture towards both its own *intrapreneuers* as well as previously disengaged yet innovative businesses. Words like innovation, agility, and rapid now litter an emerging ecosystem of novel and reformed programs. This work covers two substantial Air Force efforts–the Squadron Innovation Fund (SIF) and the Small Business Innovation Research Program (SBIR)–that seek to capture new sources of promising ideas and match those ideas to problem solvers.

The first effort this thesis evaluates is the Squadron Innovation Fund (SIF), whose inaugural iteration was in 2018. The SIF allocates discretionary funds for squadrons to address their pain-points, "building on the innovation ecosystem started [in 2017] that catalyzes Airmen to bring their ideas forward so [the Air Force] can act on the best ones" [54]. As a grassroots program it aims to redefine cultural norms to be more attentive to the insight and technical expertise of ground level workers. Originally crafted in broad strokes, the SIF challenges traditional contracting processes and is evolving as a bottom-up signal for heavier SBIR funds.

The SBIR program is almost four decades old, but in 2018 the Air Force started introducing changes to SBIR that have expanded so that in 2020 the Air Force's $1B SBIR program is awarding most of its funds through application, evaluation and

award processes that did not exist a couple years ago [66]. Under the new system interested companies face stripped application requirements and have options to apply through pitch days for an accelerated award timeline or to open topics that allow the firm to identify the problem area. These changes are ultimately intended to engage a broader base of innovative startups and small businesses.

This chapter begins with the DoD's history as the primary financial contributor to research and development (R&D). After tracing the rise of industry investment into R&D efforts, this chapter articulates the shift from a linear view of innovation that lends itself to guarded research efforts towards an open concept where confluence is key. Against this background the chapter lays out the DoD's new strategy and situates the SIF and the SBIR program among other members of an emerging innovation ecosystem.

1.2 Changes to the Innovation Landscape

1.2.1 The Origins of Direct Government Investment

Science as the Endless Frontier

At the close of World War II the Office of Scientific Research and Development faced an uncertain future. Months earlier President Roosevelt had written a letter to its director, Vannevar Bush, seeking ways to extend the wartime benefits of government research into peacetime. In an opening paragraph the President wrote, "the information, the techniques, and the research experience developed by the Office of Scientific Research and Development and by the thousands of scientists in the universities and in private industry, should be used in the days of peace ahead for the improvement of the national health, the creation of new enterprises bringing new jobs, and the betterment of the national standard of living" [88]. Vannevar Bush's response to the President remains a seminal work advocating for and outlining the government's role in the production of knowledge and its transition to impact [31].

The force of Bush's response, titled *Science The Endless Frontier*, drew momen-

tum from a war effort greatly benefited by publicly funded technology. Decades later the Gulf War again demonstrated to a global audience the advantages conferred by technology, this time in the form of communication satellites and precision strike capabilities. In addition to the direct effects, technological capabilities contribute to the credibility of a deterrence strategy, which has long undergirded U.S political influence from the Cold War to the Atlantic Alliance [49].

Government Institutionalizes Support of R&D

Following the war government programs continued to lead cutting-edge research, passing on what it deemed fit to the private sector. Nuclear technology, GPS capabilities, and early forms of the internet emerged from government laboratories and federally funded programs. Supercomputers, artificial intelligence and speech recognition were supported by DoD R&D funds in their early stages when commercial benefits were less immediate [95]. Many of academia's initial forays into information theory, computer architecture, and artificial intelligence were funded by DoD R&D funds [101]. Claude Shannon, Marvin Minsky, and Alan Turing are notable examples.

The origins of many foundational technologies can be traced to an initial investment by federal R&D funds [95]; moreover, the DoD is the primary driver of federal R&D funds, accounting for over 44% in 2020 [93]. In addition to the military technological advantages, the spillover economic effects are widely attested. According to Vernon Ruttan, DoD investment and military procurement in the 1970s and 1980s is responsible for the economic tech boom and high growth rate of the 1990s [90].

Federal R&D Investment Takes a Backseat to Industry Efforts

While many federal projects funded through the DoD have produced pivotal innovations, the government's investment in R&D has steadily declined since the Cold War. Figure 1-1 shows the rapid growth of industry R&D against a stagnant federal R&D budget. Not only has federal spending on R&D fallen relative to private sector investment, but it has continued to fall as a share of GDP. Figure 1-2 depicts this trend.

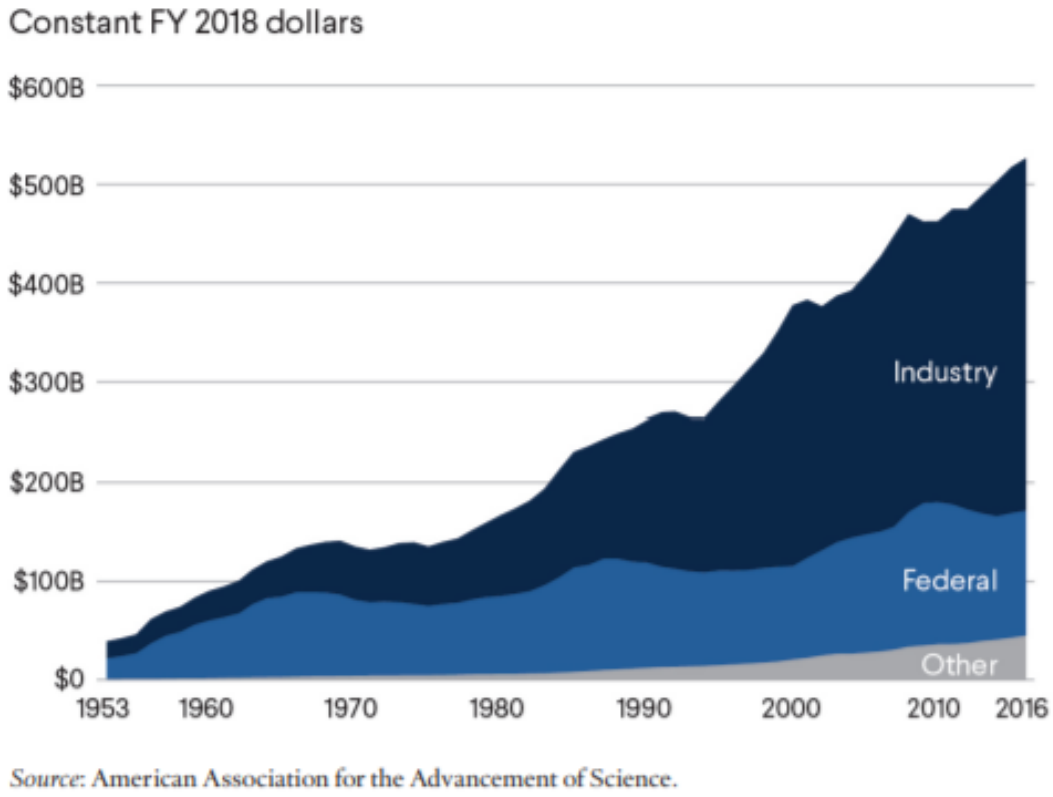

Figure 1-1: Industry commands a growing share of R&D efforts

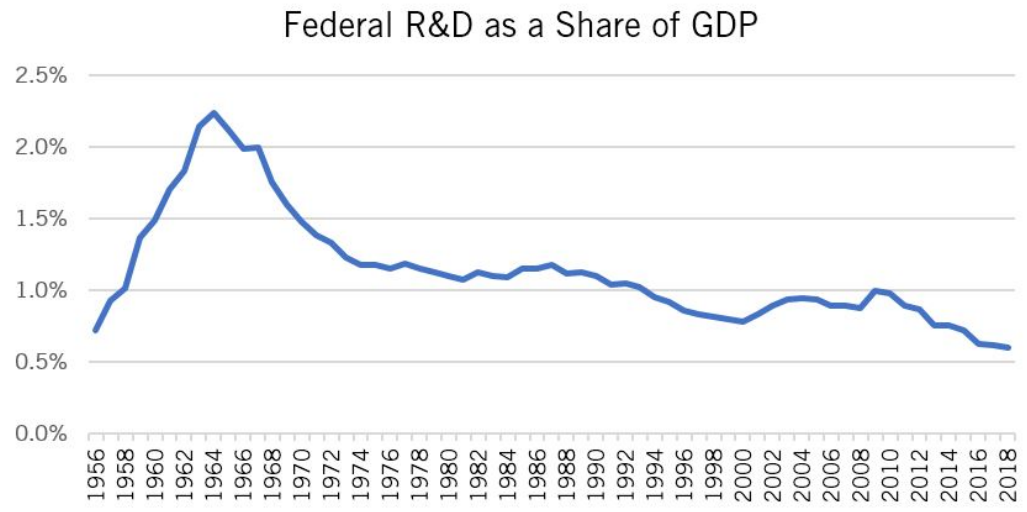

Figure 1-2: Federal R&D falling as a share of GDP. Source: Information Technology and Innovation Foundation

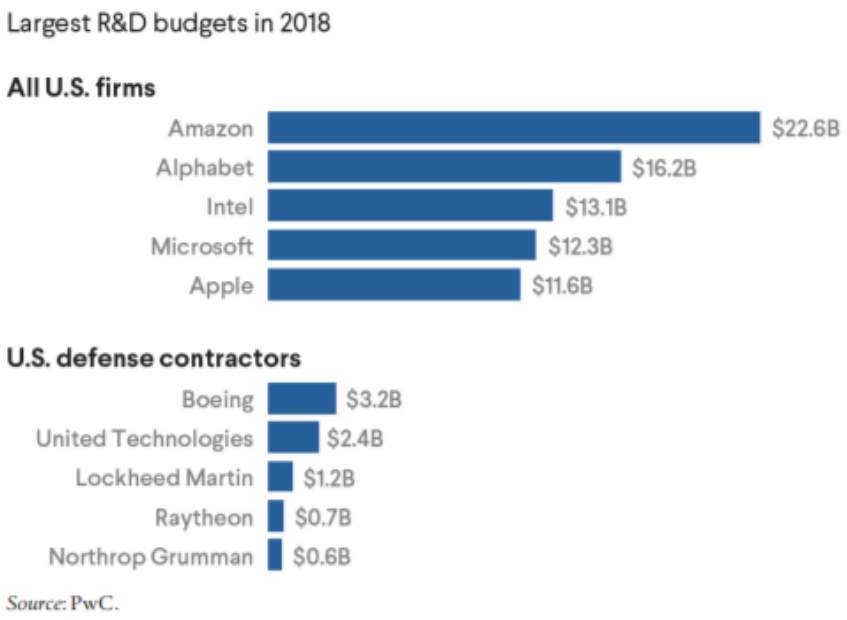

Figure 1-3: Defense contractors spend less on R&D than leading tech firms

Traditional Prime Contractors Lag Big Tech in R&D

Furthermore, the R&D budgets of DoD prime contractors dwarf that of the leading tech firms. Figure 1-3 compares the R&D budgets of the largest defense contractors to that of Amazon, Apple, and the like. According to FitzGerald et. al, traditional defense contractors are also shrinking the size of their R&D budgets over time [48].

1.2.2 Theory of Innovation

What is Innovation?

Before moving further it is worth considering the process that surrounds the production of useful systems and technologies. In the parlance of MIT, innovation is the process by which ideas move from the earliest stages of inception to impact.

The Linear View of Innovation

Vannevar Bush's report to President Roosevelt emphasized the role of basic research to set the innovation process into motion. In fact, the linear view of technological

development popular in the 1950s and 1960s traces its origins to *Science The Endless Frontier* [89]. In the words of Benoit Godin, the linear view of technological development "postulates that innovation starts with basic research, followed by applied research and development, and ends with production and diffusion" [53]. Under this lens innovation is initiated by either the technology developers in a *tech-push*, or else by market demand in a *market pull* [89]. With *tech push* and *market pull* as the two possible antagonists for innovation it follows that the government should fund the pushing-side of the innovation process because it is less likely to be supported by private sector actors.

Open Innovation

The emergence of concentrated *innovation ecosystems* in Silicon Valley, Boston, and San Francisco suggests that innovation is more about having the right groups of people together and letting them interact fluidly. Fiona Murray and Phil Budden from MIT point out in a working paper that "it is not enough to simply ramp up spending on R&D and expect the desired impacts" [81]. The movement towards open innovation reflects a general trend to intentionally widen the aperture of who is involved in the innovation process, from problem identification to technical development. This distinction is further exemplified in studies considering specific industries. For example, the life sciences industry is beginning to realize that leverage in today's highly diffuse knowledge environment hinges on the successful integration of new sources. Melese et. al point to many companies shifting their R&D expenditures externally through collaborations with small biotechnology companies and academia, signaling an adoption of a paradigm that no longer expects the next new approach to come from internal research [76].

Open innovation promotes an information age mindset that runs counter to the secrecy and silo mentality of traditional national defense laboratories and traditional corporate research labs [36]. The concept draws from a strong appreciation for external cooperation in an increasingly interconnected world. Such an emphasis on permeable boundaries however is not easily reconcilable with a military that asso-

ciates its strength and efficacy with technological superiority. Nonetheless, this is the reigning paradigm within which the DoD must reimagine its role.

Under an open understanding of innovation the space of roles and responsibilities is not neatly partitioned. Although this may contribute to more flippancy with what Marvin Minsky calls suitcase words–such as innovative, agile, or open [77]–serious efforts have gone towards a systematic characterization of a what a well-functioning innovation ecosystem looks like [79].

In summary, the linear view of technology development manifests in support for government funding early stage R&D. Supplanting this view is the open innovation paradigm, which as it gains traction is compelling the DoD to reconceptualize its posture towards a dynamic landscape of startups, private equity sources, tech giants, and universities.

1.2.3 Industry R&D is Expanding but Concentrated

It is a dangerous to presume that open innovation ecosystems are wholly replacing what has been done by the government. Investments in R&D by the private sector are highly concentrated in a few sectors. Digital services constitute the core of private sector growth, because require less up front capital, and have shorter time horizons. Figure 1-4 depicts the rise of venture capital in both overall value and deal count from 2009 through 2019. According to Pitchbook, in 2019 venture capital allocated $43.5B to software, $16.6B to pharma/biotech, $7.6B to healthtech, and $5B to cybersecurity. Together these four sectors captured half of the total venture capital for 2019 [86]. In contrast, emerging businesses that developed materials received a relatively meager $350M in 2018 [46]. In response to this concentration of equity on sectors with short development timelines, a new class of venture capital firms are setting their sights on the *tough-tech* sectors such as materials, nanotechnology, and advanced manufacturing. Although the return on investment is not as immediate, these efforts are starting to fill the funding gaps left by others [46]. Despite this movement the wealth of venture capital remains highly concentrated.

This skewed distribution of private funding has the beneficial consequence, how-

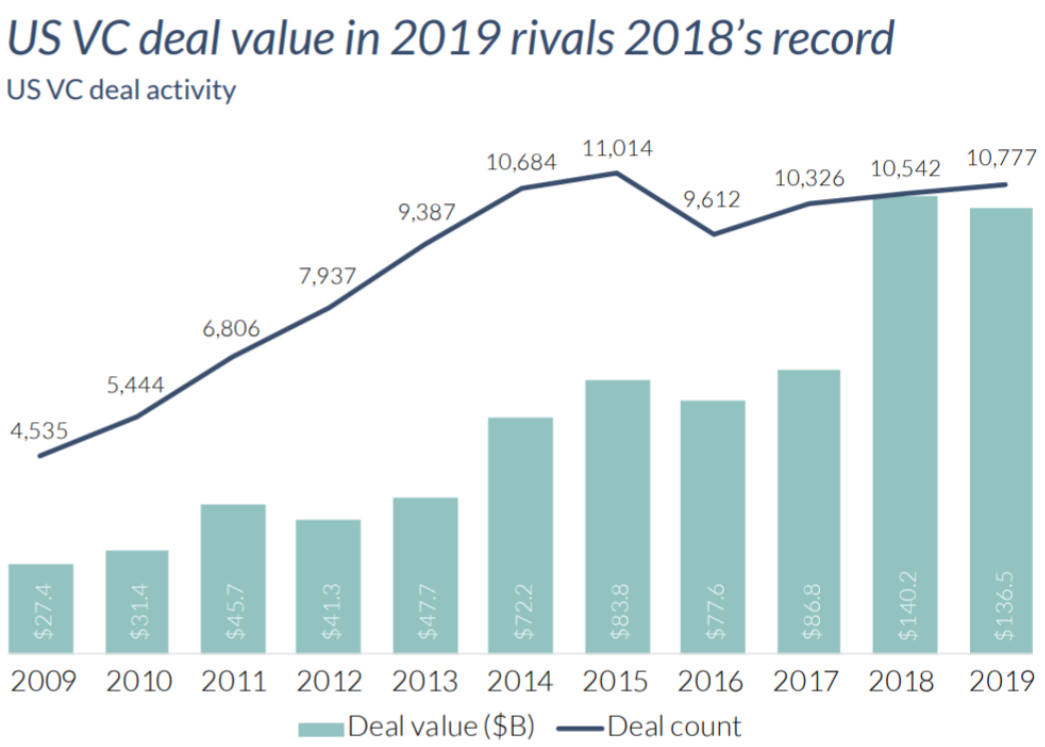

Figure 1-4: Source: Pitchbook and NVCA

ever, of empowering the fortunate technology sectors to take risks on earlier stage developments. In this new era, tech giants are taking on more audacious projects either through internal R&D groups or through acquired startups. Google exhibits examples of each. Google's moonshot factory–formally known as Google X–has spun off startups that are paving the way toward autonomous aerial deliveries and self-driving cars. In their own words, "we approach projects that have the aspiration and riskiness of research with the speed and ambition of a startup" [8]. Whether daring research projects are incubated within company R&D teams or are acquired as in the case of Google's DeepMind [94], synergy between fledgling startups and big tech firms is expanding the private sector's reach to earlier stages of development.

1.2.4 A Varied and Dynamic Threat Landscape

As succinctly laid out in *Future Foundry: A New Strategic Approach to Military Technical Advantage*, "the existing defense industrial regime is optimized to cope with

neither the rapidly evolving and varied threat landscape nor the decentralization of innovation and global proliferation of advanced technology" [48]. Threats, such as cheap consumer drones modified to carry explosives into forward operating bases, emerge without the lead-time to develop solutions required by acquisition processes developed for the Cold War enterprises of nuclear capabilities and satellites [13]. Furthermore, today's complex geopolitical context demands that the DoD respond to threats across air, space, and cyberspace.less sophisticated threats. While the DoD races China to develop hypersonic weapons and counter Iranian cyberattacks, it is simultaneously engaged in conflicts where improvised explosive devices remain a serious threat [38].

1.3 The DoD Recasts its Strategy

From the 2018 National Defense Strategy:

> *...success no longer goes to the country that develops a new fighting technology first, but rather to the one that better integrates it and adapts its way of fighting.*

Constituent components of the DoD are running with this vision. In the words of Dr. Will Roper, the Air Force's Assistant Secretary for Acquisition, "The world is changing. We have to change with it. The key is to decide which technology will be successful and being able to act on those trends with a system that is leaner, meaner and faster than our opponents" [24].

1.3.1 Agile is the New Buzzword

The DoD no longer expects to maintain its operational edge by relying on developing technology in-house, but is centering its strategy on adapting innovations coming out of the private sector.

As early as 1999 the Defense Science Board Task Force on Globalization and Security reported that DoD was "relying increasingly on the U.S. commercial advanced technology sector to push the technological envelope and enable the Department

to 'run faster' than its competitors. DoD is not a large enough customer to keep the U.S. high-tech sector vibrant" [9]. Every Defense Secretary of the 21st century took steps to restructure acquisition pathways. In a 2014 address Secretary Chuck Hagel announced a Third Offset Strategy to re-establish U.S. technological advantage through more research in robotics and autonomous systems among other things [58]. When Secretary Ash Carter took the reins he prioritized the dual-use potential of commercial developments, which he institutionalized through the Defense Innovation Unit (DIU). Another important step was the establishment of the Defense Innovation Board (DIB), whose board members were specifically recruited for their expertise outside the DoD [2]. In a 2016 speech Secretary Carter emphasized the "additional variables of speed and agility" as new requirements for the modern acquisition program [34]. When Secretary Jim Mattis took the helm he carried the torch: "Success does not go to the country that develops a new technology first, but rather, to the one that better integrates it and more swiftly adapts its way of fighting" [72]. Today, agility is a pervasive goal in the DoD. New DoD programs have *agile* in their name, and AFWERX's CEO closes emails with "Be fluid, stay agile...".

2018 as a Year of Change

Ultimately the DoD is answerable to the public. Overseeing the DoD on behalf of the public is the Congressional Armed Services Committee. The topic areas of the sessions held by the Committee reflect the nature of DoD reform efforts in 2018. Figure 1-5 conveys the focus on modernization.

1.3.2 Obstacles to the New Strategy

Reorienting the DoD towards agile engagement with increasingly open ecosystems requires overcoming cultural and procedural hurdles. In a 2018 address to the House Armed Services Committee, Eric Schmidt, Chairman of the DIB and former CEO of Alphabet, spoke curtly: "the DoD does not have an innovation problem. It has an innovation adoption problem" [92]. The following section outlines obstacles to the

House Armed Services Committee	Senate Armed Services Committee
Readiness Subcommittee on Army Futures CMD: Army Futures Command: Will it help?	Accelerate New Technology to Meet Emerging Threats
Military Technology Transfer: Threats, Impacts, and Solutions for the Department of Defense	Posture of the Department of the Army
Ground Force Modernization Budget Req for FY 2019	Army Modernization
Promoting DOD's Culture of Innovation	Department of Defense Acquisition Reform Efforts
Request for DoD Science and Technology Programs	All Arms Warfare in the 21st Century
Assessing Military Service Acquisition Reform	Reshaping the U.S. Military
Readying the U.S. Military for Future Warfare	
The Army's Tactical Network Modernization Strategy	

Figure 1-5: 2018 Congressional Hearings

adoption of innovation in the DoD.

Higher Stakes

The DoD employs technology to safeguard nuclear weapons, to provide humanitarian relief in the wake of global natural disasters, and to carry out precision airstrikes. These stakes are not just life or death but involve the stakes of taking life. Technologies designed for commercial use may not be sufficiently reliable for a deployed military environment.

Security

An open innovation ecosystem presents more points of access for nefarious actors. Putin called the controversy over Huawei the "first tech war of the coming digital age" [43]. The Defense Intelligence Agency pointed out that Chinese strategy relies not on military seizure but on economic and technological leverage through the takeover of ports, infrastructure and widespread surveillance systems [22]. In 2015 China

released its *Made in China 2025* plan which focused on becoming the global leader in technological capabilities for advanced industries [74]. Nonetheless, DoD operations require greater security guarantees on the impenetrability of its systems, although obtaining guarantees is difficult due to the nature of software-based systems and the diffusion of production.

Software-based systems are difficult to secure, especially if the developer is a small business or the product is new. That software is often released with errors is evidence by the constant updates put out by even the most prominent tech companies. Software however is a sector experiencing high growth and has the potential to improve the incisiveness and efficiency of DoD operations. In fact, according to the DoD Chief Information Officer the current push is one that aims to "shift the mindset and culture from a hardware-centric and industrial-age force to a software-driven and information age one" [40].

Verifying the entire supply chain of sophisticated technologies presents another challenge, both because the vulnerabilities of complex systems are not immediately apparent and because complex systems are comprised of myriad components from myriad sources. In one case, the Trump Administration stepped in to prevent a Chinese government-backed investment firm from buying out a US chipmaker Lattice, which is a major chip supplier for DoD systems [14].

Balancing unnecessary regulations against legitimate safety concerns will inevitably involve missteps, but nonetheless the DoD is stepping forwards. In early 2020 the DoD revised DoD Instruction 5000.02, the framework governing software acquisitions, in order to facilitate the iterative nature of software development. Specifically, this update grants intermediate decision authorities broader authority to plan and manage programs [20].

More generally, DoD is experimenting with broader authority at lower levels, but doing so exacerbates security concerns. A notable example is the Air Force SIF, a discretionary fund which demonstrates how deviating from established guidelines runs the risk of trading flexibility for security. An internal audit that coincided with the SIF's inaugural year reported that the Air Force and Army spent $32M on

commercial-off-the-shelf items (COTS) blacklisted by Congress [51]. It is likely that most of these purchases were made through Government Purchase Cards that have a $10,000 per-swipe limit and involve less oversight [51].

Reticence of Private Sector in Support of DoD Operations

Uniformed service members are familiar with the statistic that less than one percent of citizens serve in the military. An espirit de corps is furthered by unique mission sets and shared training experiences. Analogously, the high-tech community and its feeder academic institutions exist within a sphere of communal norms. While both communities share an ethical framework based in western, liberal, democratic values, partnerships between tech companies and DoD implicates civilian employees in the development of the instruments of war.

Project Maven was the military's pilot program with Google to turn expansive data stores into "actionable intelligence and decision-quality insights at speed" [64]. According to a published interview with an anonymous employee, there was internal dissent from the start [98]. After *Gizmodo* revealed to the public that Google was "helping the Pentagon build AI for drones", opposition mounted with a letter signed by over 4,000 employees to the CEO asking him to cancel the project [98].

On October 31st, 2019, the DIB published *AI Principles: Recommendations on the Ethical Use of Artificial Intelligence by the Department of Defense*. Guided by these principles, the Joint Artificial Intelligence Center (JAIC) was established to be the focal point for collaborations with industry and academia. Officially, the mission of the JAIC is to accelerate artificial intelligence delivery and adoption by the department and the military services [40]. It has components situated within universities–MIT being one of them–where students and faculty contribute to and lead projects.

Speed and Familiarity

Partly as a result of high emphasis on security, DoD acquisitions are slow-moving. Katy Person, a former Army acquisitions officer and MIT Innovation Initiative re-

searcher, neatly explains the current regulation-laden system in her survey of DoD innovation programs: "The defense acquisition process is shrouded in the legacy priority of fraud prevention. Between the Department of Defense Instruction 5000.02, the Defense Acquisition Regulation System (DFAR), and the case law accompanying seventy years of competitive contracting, the entire national security innovation base has a tough nut to crack..." [85]. Small businesses and startups have less time and administrative capacity to take on government contracts. Furthermore, many in the venture capital community advise emerging businesses to avoid working with the government because of the administrative overhead and longer timelines [33].

Compatibility

In a deployed environment, units work together across mission specialties and branches. Compatibility across platforms, then, is crucial for coordination. Beyond simply getting things to work together, platform integration raises security concerns. Consider, for example, a needed overhaul of a radio communication system. Updates to the ground radio must coincide with updates to the receivers installed in aircraft, but in a deployed environment the former falls under an Army acquisitions process while the latter depends on Air Force pathways. To address this challenge, the Joint Capabilities Integration and Development System (JCIDS) takes a top-down approach in addressing strategic operational gaps while avoiding redundant efforts across services and standardizing interdependent battlefield systems [12]. This coordination, however, comes at the cost of time. According to an Army report, consolidating system requirements through JCIDS takes 15-22 months [11].

Misaligned Incentives for Military Leadership

In his address to the House Armed Services Committee, Eric Schmidt characterized the environment that stifles *agility*:

> Some *intrapreneurs* find workarounds or receive temporary shelter from a like-minded commander, but many decision makers do not. The growth

> in size and complexity of the Department's mission and systems has contributed both to the increased friction and latency in its decision-making processes and has driven a demand for additional layers of coordination mechanisms. Over time, lapses in judgement or performance accrete additional rules, or procedures aimed at preventing those errors. Yet, the cumulative effect is disempowering for many, even for those on the frontlines. It is troubling to consider that good ideas were not implemented because of prevailing norms that reward perfunctory compliance or reticence of supervisors to consider new approaches. It is even more frustrating to see passionate service members choosing to leave the military after being continually stymied by these structures [92].

These concerns have not gone unanswered. The USD (R&E), a new position fourth in line behind the Secretary of Defense, was recently introduced to promote faster innovation and reduce risk-intolerance [75]. Such restructuring is an exogenous approach to shifting cultural norms. On the other hand, Special Operations Command consistently executes successful acquisitions programs despite facing the same regulatory structure. The Center for New American Security attributes to its command climate and culture [48]. However it is achieved, the DoD must overcome cultural inertia and risk aversion.

Summary of Obstacles

Over the last several years, policymakers and others have expressed concern that the long-held technological edge of the U.S. military is eroding due to insufficient engagement with rapidly proliferating innovation ecosystems. Barriers to engagement include higher standards of reliability and security for military systems, civilian discomfort playing an implicit role in military operations, an accumulation of regulations, and insufficient reward structures for smart risk taking. What follows is a survey of reformed and novel DoD programs that address these obstacles.

1.4 An Explosion of Efforts

Each of the six branches within the DoD are experimenting with reimagined acquisition pathways under the guidance of the National Defense Strategy (NDS). Individual branches are following up the broad strokes of the NDS with flexible, loosely defined programs of their own, while looking laterally to their sister services to evolve in lock step. Generally, individual programs have a very specific target audience, whether that is servicemen, startups, or established firms.

Army Futures Command, whose establishment was one of the most significant reorganizations in the Army since 1973 [3], presents a comprehensive notion of what renovating the innovation ecosystem looks like. According the Army Futures Command, innovation looks like delivering solutions to warfighters in a timely manner, cultivating a culture that front-loads smart risks through iteration and prototyping, and being willing to fail early and evolve together [3]. Ultimately, at the core of this agility strategy is the inclusion of more actors in the ideation and problem solving process.

1.4.1 Sourcing Ideas from the Ground Level

Innovation is best directed towards a problem, and technicians are the *intrapreneurs* best qualified to propose solutions. The Army's Program Executive Office Soldier (PEO) empowered soldiers to make suggestions directly to the PEO, and now 40% of PEO Soldier's portfolio are offshoots of warfighter suggestions [85]. The Air Force's SIF also looks internally by allocating around $20,000 in discretionary Operations and Management funds for squadrons to address problems hampering day-to-day operations.

An analogous effort in the Navy is the NavalX Agility Cell, whose stated purposed is to "serve as a matchmaker between those with ideas and those with knowledge and resources to further those ideas, and between separate labs or groups working on related projects" [44]. This framing emphasizes the sailor's role in providing ideas which engineers and businesses develop towards the end of "improving pivot speed in

bringing in new gear, and implementing new practices" [44].

1.4.2 Matchmakers

Formerly known as MD5, the National Security Innovation Network (NSIN) reaches a broader audience of university talent and startups. Similar to NavalX Agility Cell, NSIN serves as an access point for companies to engage with the DoD's unique set of technical problems. Formally situated under DIU, NSIN is tasked with creating networks of innovators [57].

1.4.3 Dual-Use

A key player within the swath of emerging programs is DIU, which focuses on well established companies whose technological capabilities have dual-use potential for military applications. DIU is strategically located in the major innovation hubs of Boston, Austin, and Silicon Valley, and is granted acquisition authorities to grant multi-million dollar contracts with well-established companies whose products are readily convertible to fill an urgent need. In their own words, "DIU is the only DoD organization focused exclusively on fielding and scaling commercial technology across the U.S. military at commercial speeds. We are focused on five technology areas where the commercial sector is operating at the leading edge: AI, autonomy, cyber, human systems, and space" [42].

1.4.4 Learning to Work with the Tech Community

Software is developed iteratively and requires regular maintenance. It is also critical in facilitating DoD operations. The open-to-close contract model, however, makes for an awkward fit. Stepping in to smooth the edges are organizations like the Defense Digital Service (DDS) and Kessel Run. The DDS works within simplified acquisitions and Other Transaction Authorities (OTAs) to quickly deliver digital products [85]. In a similar vein, the Air Force's Kessel Run program fashions itself after its peers in the software world, employing modern methodologies such as user-centered design,

extreme programming and lean product development. In its iconic example, Kessel Run automated the flight-planning of KC-135 tankers, displacing a system where flight plans were hashed out on a white board with movable checkers [103]. Moreover, such programs are an opportunity for the DoD to learn how to cultivate and maintain relationships with companies who do not want to be beholden to a single stakeholder.

1.5 Thesis Roadmap: SIF and then SBIR

Underlying these efforts is an overriding conviction that the DoD must widen its aperture to a broader set of potential partners. And while many programs are seeking to do this, this thesis focuses on the SIF and SBIR. Specifically, chapter two evaluates the SIF, a grassroots innovation experiment. Chapter three lays out the purported benefits, structure, and controversies of the SBIR program, culminating with an exploration of the radical changes of SBIR under AFWERX. The last chapter carries out a rigorous econometric analysis to provide evidence that the new SBIR special topics are expanding the SBIR applicant pool in valuable directions.

Chapter 2

Squadron Innovation Fund

Introduction

The 2019 Squadron Innovation Fund (SIF) distributed $70M in discretionary spending to stimulate and leverage the technical expertise of Air Force military members, hereafter referred to as Airmen. Conveyed and organized in rather broad strokes, the second evolution of the SIF in 2019 revealed pertinent trends, which this chapter extracts through data analysis and interviews. To highlight a few, many projects could have been funded via standard budget requests, a high proportion of projects fell right under the $10,000 Government Purchase Card (GPC) limit, and many projects targeted efficiency hacks through means that would require formal approval authority to scale across the force. This analysis argues the most immediate benefit lies in indirect, higher-order effects such as facilitating communication across mission groups and highlighting problem areas for heaving funding sources.

The Approach

The intent of this chapter is to understand how these funds were spent, connect trends to potential explanations, and propose focus areas for future iterations. This framework was developed with Air Force decision authorities in mind.

Based on this, this paper is structured in the following way. Section 2.1 parses

the notion of innovation within the Air Force context. Section 2.2 situates the SIF within the larger DoD innovation ecosystem. Section 2.3 explains how the money was spent. Section 2.4 suggests a way forward based on lessons learned for managing grassroots innovation from the second largest mining company in the world. Section 2.5 gathers recommendations. Section 2.6 discusses salient takeaways, and Section 2.7 summarizes the contributions of this chapter.

2.1 Innovation and the Air Force

2.1.1 Parsing Innovation

The United States Air Force prides itself on a history of innovation, but innovation is a suitcase word–almost anything can fit in it. A distinction between process and impact lends itself to a more precise discussion of the SIF.

In step with the parlance of MIT's Innovation Initiative, innovation occurs when ideas impact the way that the Air Force operates. Some have sought to further break down this concept by partitioning innovation along the dimension of the level of impact [55]. Other perspectives focus on the process that brings about the change [55]. For the sake of more flexibility in articulating the kind of innovations resulting from the SIF, this paper considers both perspectives–that is, with regards to the level of impact and the process.

Considering the Level of Impact

Incremental, breakthrough, and transformational describe impact level. Incremental innovation looks like cost reductions, size adjustments, more integrated functioning, more automated processes, and other efficiency hacks. Breakthrough innovation meaningfully changes the modus operandi and renders something demonstrably new. This might look like a laser-scanning device that allows maintenance crews to reverse engineer deteriorating parts through on-the-spot additive manufacturing. Transformational innovation expands the capabilities provided to the Combatant Commander.

Examples of such are the development of strategic reconnaissance during the Cold War and precision strike in the late 1980's. The scope of the SIF lends itself primarily to incremental innovations, with potential for breakthrough innovation albeit indirectly.

The level of impact of an innovation is not directly tied to the sophistication of technology, nor is it tied to level of authority. If Air Education Training Command introduces a streamlined email alternative for its 50,000 person force, this is an example of incremental innovation. Further, it is important to note that innovation is not confined to technology, but also encapsulates adjustments in policies and procedures. For example, a squadron commander may try disseminating daily information through morning briefings instead of per email.

Considering the Process

Innovation can also be described by the process that brings it about. In a report of major Air Force Innovations, RAND extracts three processes–immediate-adaptation, short-cycle and long-cycle [56]. Immediate adaptation happens as units adjust tactics and techniques on a sortie-by-sortie basis. Short-cycle innovations arise out of field exercises that seek to solve strategically important operational problems. Long-cycle innovations involve the development of technologies and platforms over many years. Although these categories do not map perfectly onto the SIF project space, distinguishing how squadrons approach innovation projects is of interest.

2.1.2 The Air Force-Innovation Fit

The Air Force Prizes Innovation

Affectionately referred to as the "Chair Force" the DoD's third largest branch employs high-tech equipment from the F-22 Raptor to satellite arrays. For an organization that relies on technique to provide leverage, innovation is an appealing concept. The new Air Force vision statement reflects a serious intent to place Airmen at the center of the innovation enterprise: *The World's Greatest Air Force–Powered by Airmen,*

Fueled by Innovation. The emphasis on a bottom-up approach is further reinforced by the former Chief of Staff's mantra that "The squadron is the heartbeat of the Air Force". That squadrons are typically smaller than one hundred people speaks to the concerted focus on empowering lower levels to enact the changes they want to see.

Airmen Contributions are not Visible

The subtle nature of incremental innovations means that the contributions of airmen are not visible. One way to overcome this is sharing stories of airmen-led initiatives in speeches. General Goldfein was a particularly memorable speaker, and he hinged his speeches around airmen at relatable responsibility levels [54]. Stories are crucial in bringing to life Airmen's contributions to innovation because Airmen are not involved in the development of technology and innovation is most self-evident in novel technologies.

Air Force technology is developed through contracts. Even officers whose primary job title is engineer are rarely practitioners, but are project managers. In a 117-page report on innovation in the Air Force, the RAND Institute centers its analysis on case studies of major technology developments such as strategic reconnaissance, nuclear survivability, suppression of enemy air defenses, and precision strike [56]. Even though the report finds that pivotal innovations in the Air Force are more likely to derive from the efforts of individuals and units rather than formalized doctrine or organizational structures, Airmen are left with obscure pathways from their actions to impact. Ultimately, building a narrative that places Airmen as key players in Air Force innovation is difficult because innovation is most readily associated with technology and our Airmen are not developing technology.

SIF Contends Against Risk Aversion

The same report emphasizes that "identification and framing of strategically important operational problems are more likely to lead to innovation than technological change" [56]. Airmen are hands-on with day-to-day operations and are consequently well-situated to identify problem areas, particularly those inhibiting efficiency. The

default culture of the military, however, frustrates efforts to affect change from the lowest levels. High stakes, hierarchical rank structure, and strong sense of tradition are primary barriers to low-level initiatives. Change is risky when compliance triumphs over results and ingenuity is set aside in favor of consistency. Furthermore, levels of bureaucracy tend to diffuse ownership, leaving those who take the road less travelled finding themselves outside the safe zone. As Eric Schmidt attested to Congress, "although some airmen find cover from like-minded commanders, most do not" [92].

A report published from Air War College argues intrapreneurship from airmen is unrealistic in an organization that reinforces self-restraint, rewards group-think, and treats white space as wasted space [47]. As a remedy, the report recommends recruiting creative personalities, training in divergent thinking, providing time for incubation, and promoting innovative leaders. Instead of waiting for a new generation of leaders, the Air Force should follow the DIB's recommendations and "initiate an education and training program to expose [current] DoD leaders to technologies and business practices... to increase the rate of technology adoption and overcome institutional barriers within individual organizations" [41].

The structure and focus of military organizations do not necessarily preclude bottom-up innovations. The hierarchical structure of the military can be fertile ground for innovation. Lines of responsibility are explicit in organization charts and reinforced with rank structure while feedback mechanisms are routinely emphasized. In practice, implementing bottom-up feedback is difficult because every idea cannot be actualized and filtering the most promising ideas takes time.

A detailed account of a successful Air Force grassroots effort is presented in RAND's report. The report traces the origin of the Wild Weasels, a code name attributed to fighter aircraft bearing anti-radiation missiles and tasked with the suppression of enemy air defenses [56]. Aviators in Vietnam experimented with and developed the tactical approach where one F-100F jet armed with ECM pods marked targets for four F-105Fs jets armed with unguided bombs [60]. From 1966 to 1968 the strategy progressed to include three aircraft, novel missiles and ECM-mounted sys-

tems. With a direct line of communication to the commercial companies, the aviators formed a strategic capability still implemented, now known as Suppression of Enemy Air Defenses (SEAD). This ingenuity is what the SIF seeks to inspire. In this case the problem was concrete and the aviators recognized their agency in the development of the tools they would rely on.

2.1.3 SIF Targets Culture

Since the Air Force favors going over rather than through obstacles, a key to working smarter is through incremental adaptations. And historically, units and individuals have initiated these improvements [56]. Therefore, an understanding of innovation that looks for sophisticated technological developments overlooks contributions from Airmen.

It is unreasonable to expect the SIF to fund new armaments for the F-35, but there is room to reconsider old ways of doing things, update outdated equipment with commercially available products, and give airmen voice in identifying operational inefficiencies and proposing solutions. Incremental improvements may not get a lot of attention but they are foundational to an efficient, deft Air Force. Being at the ground level, airmen are intimately familiar with inefficiencies. More generally, inefficiency are anathema to U.S. military culture [102]. And although replacing a wildly inefficient thirty-year-old washer will not be mentioned in RAND's next review of Air Force Innovation, building a culture that recognizes these efforts is paramount. Unfortunately, the main mode of Airmen contributions to Air Force innovation is not easily recognized, commended or expected. Hence the SIF's intent to empower grassroots initiatives by directly supporting airmen initiatives with discretionary funds.

Executed through AFWERX: the Air Force's Innovation Catalyst

While the Air Force prides itself on a history of innovations, a proclivity towards change is not the natural disposition of large, hierarchical organizations. To the end of fostering a culture of innovation, the Secretary of the Air Force established

AFWERX in 2017, with innovation bases in DC, Austin, and Vegas. In its external arm, AFWERX engages industry through challenges, technology accelerators, and a new class of SBIR contracts. Internally, the Air Force looks to its own technical experts. AFWERX facilitates a decentralized network of local touchpoints called Spark Cells across Air Force bases, holds shark tank competitions to showcase airmen ingenuity, and maintains an online platform–IdeaScale–for airmen intrapreneurs to share their ideas, comment on other proposals, and track the progress of projects. Breathing life into the vision of bottom-up innovation, the SIF appropriates money for airmen to solve the problems staring them in the face. A discretionary fund, known as the Wing Innovation Funs, predates the SIF but it was a smaller amount and got bogged down into higher-level initiatives [65].

SIF is A Step Towards Open Innovation

This departure from traditional funding mechanisms reflects an underlying ideological shift towards open innovation. That open innovation underlies the DoD-wide innovation strategy is evidenced by the focus on dual-use technologies. Professor Chesbrough, originator of the term *open innovation*, says that "[open innovation] is a more distributed, more participatory, more decentralized approach to innovation, based on the observed fact that useful knowledge today is widely distributed, and no [organization], no matter how capable or how big, could innovate effectively on its own"[35]. Chesbrough goes on to distinguish the two facets of open innovation: "One is the 'outside in' aspect, where external ideas and technologies are brought into the [organizations's] own innovation process. This is the most commonly recognized feature of open innovation. The other, less commonly recognized aspect is the 'inside out' part, where un- and under-utilized ideas and technologies in the [organization] are allowed to go outside to be incorporated into others' innovation processes" [35].

This framework suggests that the Air Force has much to gain from the integration of external ideas and technologies, a side being pursued through AFWERX's restructuring of SBIR. The complement to *outside in* is allowing internal ideas and technologies to be developed by others, and the SIF is situated to identify the most

pressing problems and promising ideas. Relative to its sister services, the Air Force is more amenable to bottom-up feedback, but as Captain Arora–the capability lead for the SIF–attests, there is certainly room to better leverage the ideas of airmen at lower responsibility levels [32].

2.2 What Has Happened Thus Far

2.2.1 Messaging

As officially expressed, the desired end product of the SIF is a more lethal and ready force[54]. The approach is informed by the conviction that the squadron is the heartbeat of the Air Force. To this end, squadrons were instructed to invest in a culture of grassroots innovation (*Start Small*), expand the existing solution space (*Think Big*), and scale the best ideas (*Scale Fast*).

The allocation of discretionary funds at this level is unprecedented in the military, but it makes sense that a branch which prides itself on going around obstacles–instead of through–is leading the charge. General Goldfein and former Secretary Wilson hope that SIF unleashes the brilliance of airmen by creating an environment where young "folks with good ideas actually can get a hearing" [54]. To do this, Goldfein calls on commanders to champion the ideas emerging from the ranks of intrapreneuers. Consistent with the intent to push discretion to the squadrons, the announcement of the fund was accompanied by little guidance and implicitly carried a no strings attached slogan [1] [39]. To understand the general sense of shock, confusion, and unease among squadron commmanders [65], there are two things to consider. First, those who work at the hands-on level (maintaining aircraft, e.g.) are used to accepting their equipment and procedures as their inherited lot, handed down from nebulous upper realms. Furthermore, more agency is discomforting when strict operating guidelines are habitually relied upon as external checks.

It turns out, however, that painting in broad strokes is a well-documented ap-

[1] This has frustrated retroactive analytical efforts, hence the reliance on soft-information such as interviews to generate after action reports.

proach to managing new strategies within sophisticated organizations. As early as 1982 James Quinn of Dartmouth noted that organizations rarely follow pre-baked *rational-analytical* systems but successfully evolve in a fragmented way with a high degree of intuitive content [87]. Broad strokes give space for the SIF to evolve within a dynamic innovation ecosystem as intuition accumulates and promising trends recognized.

2.2.2 What We Already Know

Reflections on the first year of the program are limited because there was no centralized effort to collect data on what the money was spent on. In lieu of hard data, AFWERX sponsored an after action report through a third party, whose analysis relied on 39 interviews with airmen across responsibility levels.

The report finds the benefits of the program would be amplified if there was more structure to the program [16]. While the fund instilled a sense of agency and spurred cross-unit conversations, outcomes revealed a need for better coordination and education on what innovation looks like. Financial, legal and contracting offices had difficulty approving plans within the legacy acquisitions framework, so some squadrons resorted to micropurchases to buy items on their unfunded wishlists such as iPhones, because purchases under $10,000 require much less paperwork [16]. Although some bases benefited from the presence of Spark Cells, many airmen felt lost trying to navigate this new innovation ecosystem. Moreover, squadrons had difficulty coordinating on more ambitious projects. In a bit of unintended irony, the report's recommendation for a platform to share ideas and coordinate efforts across squadrons is a perfect description of IdeaScale, which was rolled out with the introduction of the SIF. Understandably, the report observed most squadrons pursuing incremental improvements.

Quantified data is not completely absent from the 2018 program. The Air National Guard gathered information directly from their units, and according to Pentagon officials, the behavior within the National Guard seemed representative of what was occurring within the Total Force [39]. Figure 2-1 represents 15% of the SIF in 2018.

Uncertainty surrounding whether the funds would arrive made commanders hesitant to authorize transactions, and because the funds did not arrive until June, there was a limited execution window. Over half of the acquisitions were information technology, then material solutions, with 12% dedicated to training and the rest towards miscellaneous purchases. A great majority of the products were commercially available products, or commodities off the shelf (COTS).

2.2.3 The Stage is Set

Thus far, this chapter presented the SIF and explained its intent to formalize institutional support of bottom-up, decentralized innovation. In addition to this, this chapter covered the available data from the SIF's incipient year. The rest of the paper builds on this foundation by outlining the major trends, showcasing typical examples, and extracting key insights from empirical analysis and semi-formal interviews.

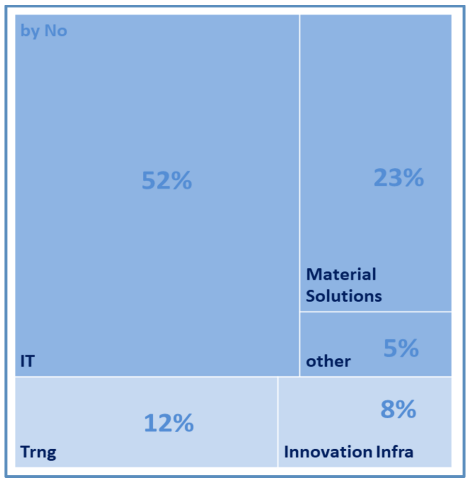

Figure 2-1: 2018, National Guard

2.3 Analysis

The following section describes how and why the funds were spent. It accomplishes this by first explaining the methods, then presenting the empirical results through two visualizations, and finally extracting and illuminating the primary spending trends.

2.3.1 Meta Analysis

As expected for an experiment with 3,500 trials, there was variation in how squadrons used funds, so I start by outlining the general trends.

In the broadest sense, the money extrapolated the normal use of Operations and Maintenance (O&M) funds. In fact, the funds were colored as O&M money. [2]. Some units admitted to not knowing whether projects were funded under the SIF or normal O&M allotments [65]. Many projects targeted low-hanging efficiency gaps through updating equipment and infrastructure. In a less inspiring trend, a smaller proportion were directed towards buying furniture or replacing monitors. Only a very small proportion of projects actively expanded capabilities, which makes sense given that O&M funds are more effortlessly applied towards things that have already been acquired by the government. Efforts coordinated across MAJCOMS showcased projects that transcended COTS and even paired with RDT&E money on Phase III SBIR projects. For example, Pacific Command appropriated $200K to develop data visualization software to support better decision making regarding the distribution of Air Force Global Strike Command's resources [29].

Data

These macro-level insights were drawn from interviews and a randomized selection and read-through of 300 of the 1,200 project descriptions posted to IdeaScale by the beginning of August 2019. After skimming project descriptions and formulating a mutually exclusive and exhaustive framework for impact area and solution type, each project was read and marked for both of these dimensions. Although the form on IdeaScale posed a host of questions [3], many were left unanswered. The most useful information was in unstructured text descriptions [4]. Figure 2-2 captures the essence of how squadrons described their projects in a word cloud. The response rate among the squadrons by August 5th 2019 was upper bounded by 30% as some squadrons split funds across multiple, separately reported projects. For the 3,500 squadrons

[2]Operations and Maintenance Funds fund expenses such as civilian salaries, travel, minor construction projects, training and education, depot maintenance, stock funds, and base operations support

[3]The questions ranged from "What problem is this project trying to solve?" to "How much money has been obligated?". Fortunately, this latter question was mandatory, which provided the data for analyzing project costs seen in Figure 3

[4]The official receipt trail is backdoor through contracting in Form 9's that are unfortunately not aggregated above the Wing level[102]

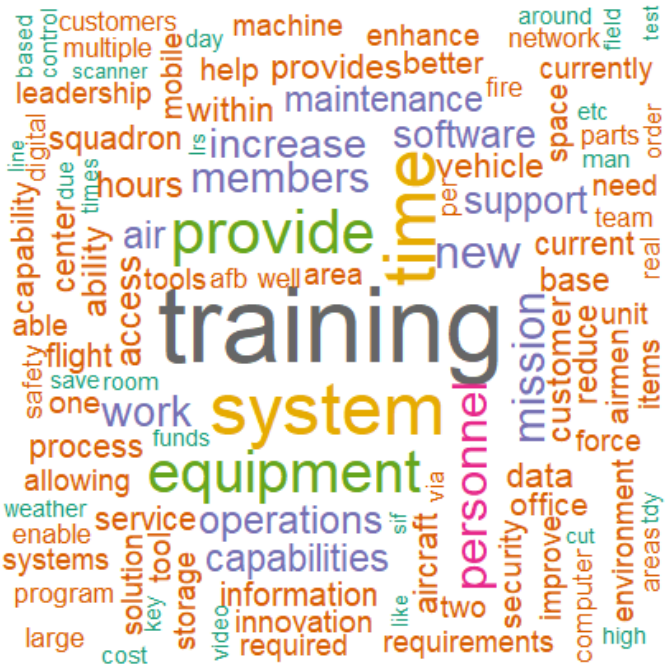

Figure 2-2: Word cloud generated from 1,200 project descriptions

that received SIF money, approximately 1,200 reported projects by August. It is also reasonable to suspect some level of selection bias among the squadrons who chose to report their projects, although a qualitative statement on the nature of the bias would be conjecture.

Distinguishing by Solution Type and Solution Impact

So what did the squadrons use their money on? The high level categories that best capture the types of projects are *Equipment/Infrastructure*, *Software*, *Technology*, and *Training*. Figure 2-3 breaks these down in a more granular fashion. While the solution type answers the *what*, understanding the *why* is critical if we are to understand what the spending habits reveal about the state of the Air Force. To this end I categorized the solutions by their impact. Inferring the intended impact area was straightforward because each project report stated the motivation for the project. Figure 2-4 details the distribution of the project across impact areas.

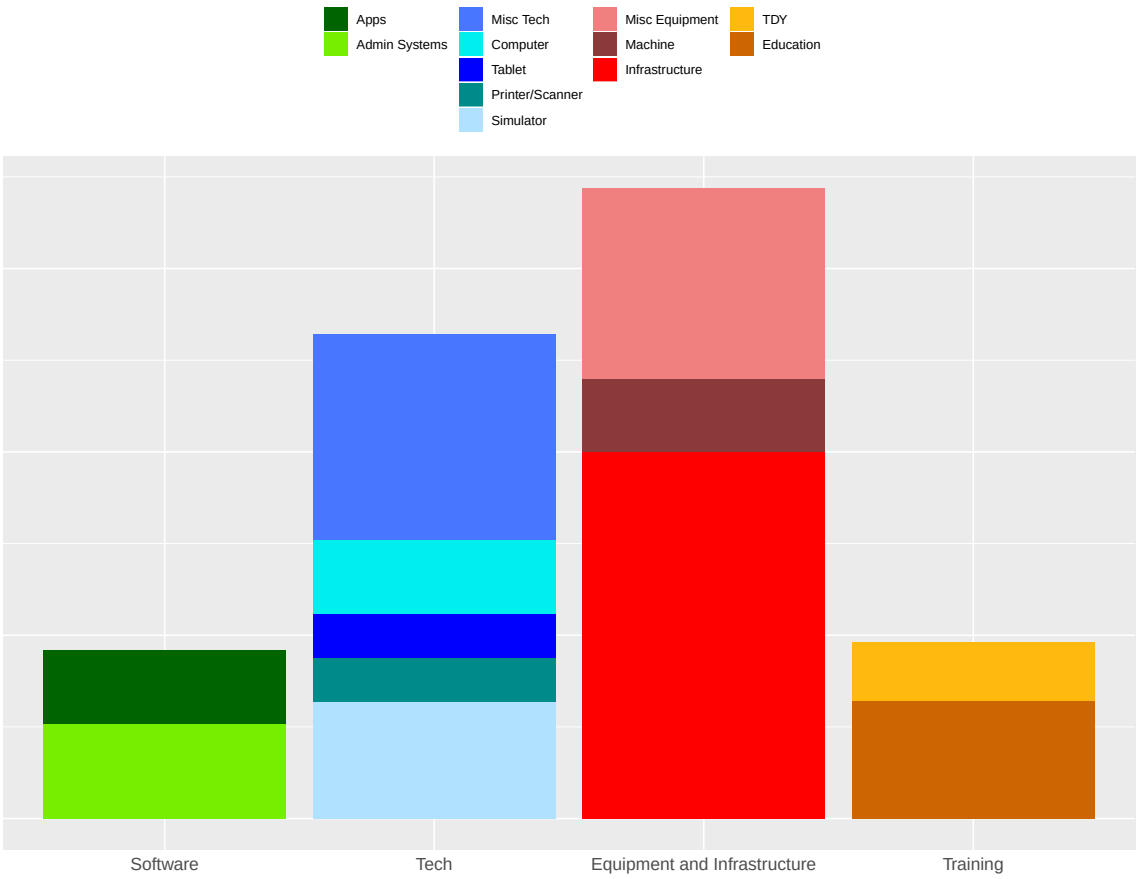

Figure 2-3: Solution Type. N = 300

Apps: Software Licenses, App for Lodging Facility Check-in
Admin. Systems: Interactive Maintenance Database
Misc. Tech: Wireless Headphones, Smart Boards, Thermal Cameras
Misc. Equipment: Emergency Kits, Customization for Recruiting SUV, Gas Generator
Machine: X-Carve Machine, Automatic Pallet Wrapper
Infrastructure: Furniture, Customer Feedback Kiosks, Mobile ECP Gate Shack
Education: Excel/Pwpt Training, Symposiums, SIPRNet Onsite Training

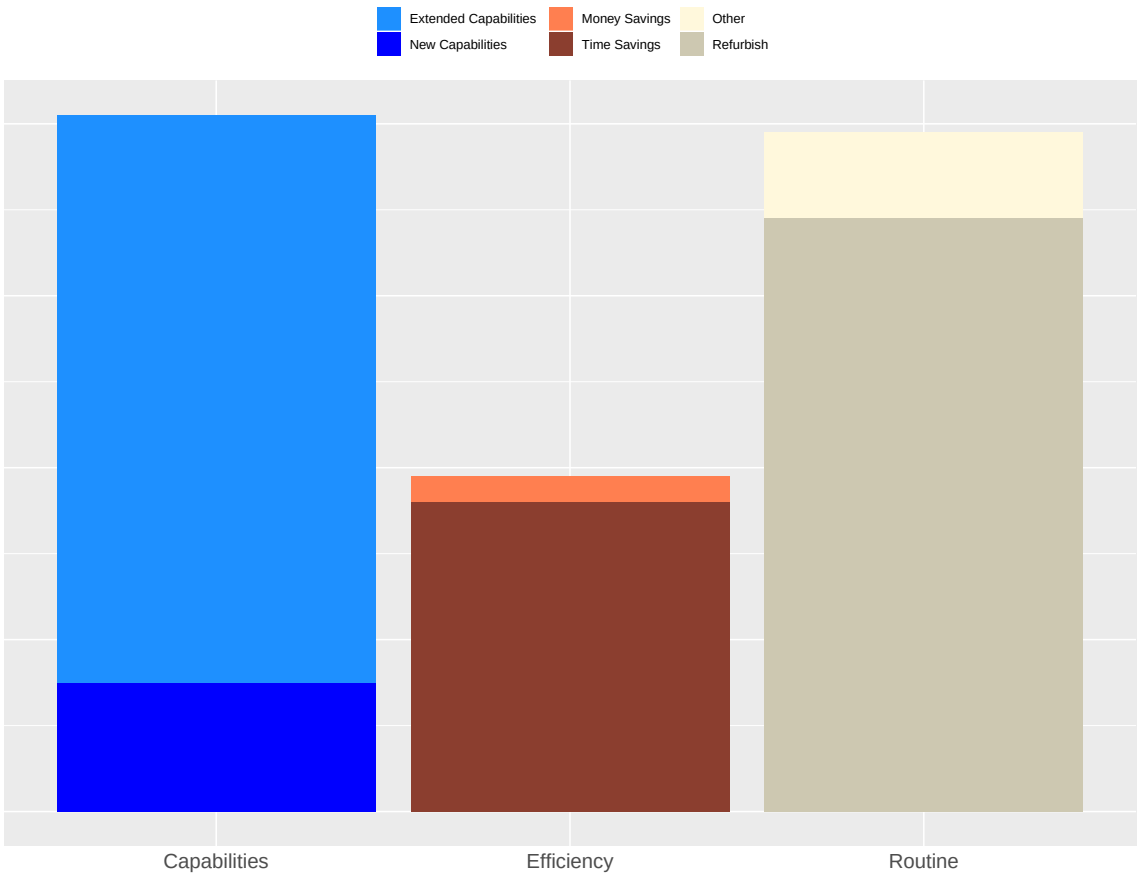

Figure 2-4: Impact Area. N = 300

Extended Capabilities: Compact/Higher-Resolution Thermal Cameras, Programmable Pop-Up Shooting Target
New Capabilities: CAD Software for Prototyping, Fitness Watches, Laser-Scan Device for Reverse-Engineering Parts
Money Savings: Preventative Maintenance Aileron Patch, Onsite OSHA Training in lieu of TDYs
Time Savings: Medical Clinic Kiosk, Additional Mail Barcode Scanner
Other: Simulator for Missile Field Vehicle, Push-button Pedestrian Crossing
Refurbish: Furniture, Replace Deteriorating Structural Components of Firefighting Training Facility, Higher-resolution Monitors

2.3.2 Elaborating on Categories through Examples

This next section illuminates the nuances of the main modes of spending.

1. Addressing inefficiencies with COTS
2. Extending capabilities by catching up with the private sector
3. Paperclips and keyboards
4. Expanding capabilities

Addressing Innefficiencies with COTS

Many projects involved squadrons addressing low-hanging inefficiencies by updating equipment and processes. One squadron purchased a washer and dryer system for bio-hazard gear, saving over 700 hours annually in lieu of hand washing. Another squadron independently purchased decontamination kits that rely on pressure instead of chemicals. If these squadrons were aware of each other's efforts, best practices would advance in lock-step as evaluated by the airmen on the ground. Unfortunately, there was no dialogue between these projects on IdeaScale.

Consistent with the theme of washers and dryers, a flying unit bought a washer and dryer so that flight suits could be cleaned on base instead of contracting it out. Regardless of whether this squadron could have afforded this change under standard O&M funds, the emergence of these extra funds encouraged a re-examination of possible inefficiencies in daily operations. Another washer/dryer purchase replaced a set that was almost 30 years old and terribly energy inefficient.

Arguably less flashy, but similarly efficient, one squadron installed movement activated lighting because approximately 30% of the building energy costs derived from lighting. In another example, an automated pallet wrapping system for loading crates onto aircraft displaced dangerous and more time intensive procedures.

Not all the projects incorporated new tools or updated infrastructure. Some squadrons funded travel expenses for Subject Matter Experts (SME) to train their workers or invested in online training modules for excel. Whether or not these projects

could have been funded under a previous budget request is indeterminate, but the SIF certainly encouraged squadrons to identify inefficiencies in out-dated processes and equipment. And although washers and dryers may not sound particularly innovative, such purchases are a better allocation of resources than blindly resorting to iPads.

Extending Capabilities by Catching Up with the Private Sector

Another class of purchases were similar because they filled in obvious cracks, but did not directly address efficiency issues. These projects must have been on the wish-list for quite some time. Noise cancelling wireless headphones for those in the workshop and more compact thermal imaging cameras with higher resolution for firemen. Similar to the previous category, they address pain points readily perceived by those working at the hands-on level. These projects may enhance efficiency but do so in downstream effects.

An illustrative example is a firefighting unit that acquired more compact, higher resolution thermal imaging cameras. Beforehand, the firefighting unit still had the capability–at least on paper–to see through smoke. The updated cameras, however, extended the firefighters functional ability to maneuver in tighter spaces and more readily identify trapped victims.

Traditionally, upper level management owns the responsibility to pick out the most pressing technical deficiencies through the smoke and mirrors of a top-down acquisitions system. In cases such as these, the SIF leverages the hands of familiarity of individual units to pick out limiting factors.

Furniture and Monitors

While some squadrons acquired 21st century washers and dryers, other squadrons mixed SIF funds imperceptibly with standard operating funds that could have been purchased in an annual budget request. This class of purchases is indistinguishable from routine O&M spending. As seen in Figure 2-3, around 30% of projects were some sort of routine purchases such as furniture or new monitors. Weed trimmers and button activated pedestrian crossing signals also fit this category. This class

of purchases may have imparted an intangible boost to the work environment by making employees feel valued, but they are not innovative. Given the many projects that belong to this category, it is worth discussing potential causes. The purchase of weed trimmers and furniture could signal a lack of basic resources, or these projects could have been the alternatives to projects stymied by the legal and contracting issues highlighted in the 2018 third-party report [16].

Expanding Capabilities

In contrast to the last category, a few examples rose to the top by way of fielding novel ideas. One Combat Training Squadron purchased field-durable projectors so that survival training could be taught in the operational environment. In another case, an Equipment Maintenance Squadron purchased a laser scanning device to reverse engineer aircraft parts that either have no blueprints or have gone out of production. This project sketches out a way forward as the Air Force tends to its aging fleets. The service life of the B-52 aircraft keeps getting extended and is currently projected to exceed 80 years. These are not extensions of previous capabilities, such as the updated thermal imaging cameras or washers and dryers. Instead, they change how the Air Force operates, even if only at a tactical level. Instead of watching PowerPoint in a classroom, survival school students with the Combat Training Squadron are in the field. Instead of taking apart old aircraft for spare parts, or waiting for parts to be hand fabricated off-location, replacements parts are hand-scanned and refurbished on the spot. Such examples were however not the norm.

2.3.3 Key Takeaways

Opportunity to Scale Domain-Specific Projects

That squadrons are organized around a mission set presents an opportunity to scale the most successful projects within similar squadrons. As of August 2019 IdeaScale was not specifically coordinating interactions between squadrons with the same mission set. Anecdotally, coordination between geographically separated units occurred

through other means.

Formalizing relevant communication pathways could be done by grouping the projects by mission set on IdeaScale. In this setup, a Force Support Squadron considering how it might want to use its funds can browse projects on IdeaScale and quickly find that another Force Support Squadron recently rolled out an app for lodging guests to check-in and replace lost keys without using the front desk. Returning to the Combat Training Squadron's purchase of field durable projectors, other SERE units may not know these projectors exist.

In addition to expanding the pool of ideas, squadrons could compare different approaches to the same problem. One notable example were two squadrons that independently bought washer/dryer systems and pressure based decontamination kits to modernize the process for cleaning protective biowarfare gear. As originally pointed out by DCode's report, the SIF spurs communication between siloed units. IdeaScale is situated to better facilitate communications, particularly between squadrons with the same mission set. When projects are easily sorted by mission-set on IdeaScale, the best solutions will scale across the force. A sorting feature would also streamline the MAJCOMs ability to pick out projects relevant to their mission set. This benefit is recursive through the hierarchy. [5]

Modernization in lieu of Innovation

For the first iterations, the SIF is more aptly understood as a modernization fund as squadrons fill in the cracks left by 30 years of a stiff acquisitions structure. Under the traditional top-down acquisitions structure, products become outdated and redesign or replacement is cost prohibitive [6]. A particularly pertinent problem for software acquisitions, these downfalls were the impetus for Kessel Run and for reforms to DoD instruction 5000.02 [7].

[5] As of August 2019, IdeaScale had a search bar but this was only helpful if you already knew exactly what project you had in mind. Tags are added by squadrons when they input their ideas, but they have become superfluous and unused.

[6] Joint Capabilities and Integration Development System (JCIDS) seeks to capture the pros of top-down acquisition processes in avoiding redundancies and standardizing interdependent battlefield systems

[7] 5000.02 governs software acquisition

Many projects suggest that outdated tools and infrastructure is pervasive and deemed by many squadrons as a primary obstacle to efficacy and efficiency. From the projects posted to IdeaScale, approximately 30% of projects (See Figure 2-4) were directed to refurbishing standard operating materials.

The majority of projects (85%) were realized through COTS [8]. In fact, many of the purchases fell right under the $10K mark, which is the limit before heavier paperwork is required to approve a purchase. Figure 2-5 shows that purchases just under intervals of 10K were five times more frequent than expected under a consistently shaped distribution. One explanation is that squadrons were unsure whether projects would be approved under a more regulated process. Perhaps moderating this concern is that many companies are aware of this limit and intentionally price their products below these cutoffs. Anecdotally, many projects included furniture, iPads to speed up check-in lines, or machines that automate processes by rolling up firehoses or securing pallets for transportation.

By and large, the purchases did not transform the way the Air Force operates. Innovation is driven by problems, and the problems that concern high level leadership are different from those of the airmen who spends most of her hours cleaning gas masks. Operators are intimately familiar with what is failing and are naturally invested in making their job more efficient.

Projects demanding coordination across systems and authority levels were less frequent. Higher authority levels have greater capacity to coordinate what John van Maanen denotes sequential and interdependent tasks [25]. The low-level discretion of the SIF also runs the risk of converging to preconceived ideas of what right looks like.

[8]COTS introduce security risks. Slack may be popular among squadrons because it is a more convenient means of sharing files and communicating with fellow crew members, but does shifting communications to private hand-held devices preserve security? A internal inspection revealed that together, the Air Force and Army spent $32M in FY18 on COTS blacklisted by the government using Government Purchase Cards (GPC) [51], although the audit admitted not being able to ascertain the number and value of COTS information technology items purchased by Air Force GPC holders because it combined requests for pricing with actual purchases made. Most of the transactions under the SIF were carried out with GPCs. It is hard not to wonder how many of these purchases were carried out under the SIF. The SIF's "no-strings attached" message conflicts with the DoD's identification of inadequate supervisory involvement and disregarded internal controls as the most frequent cause of Antideficiency Act violations (Financial Management Reg. Vol 14 Ch 2)

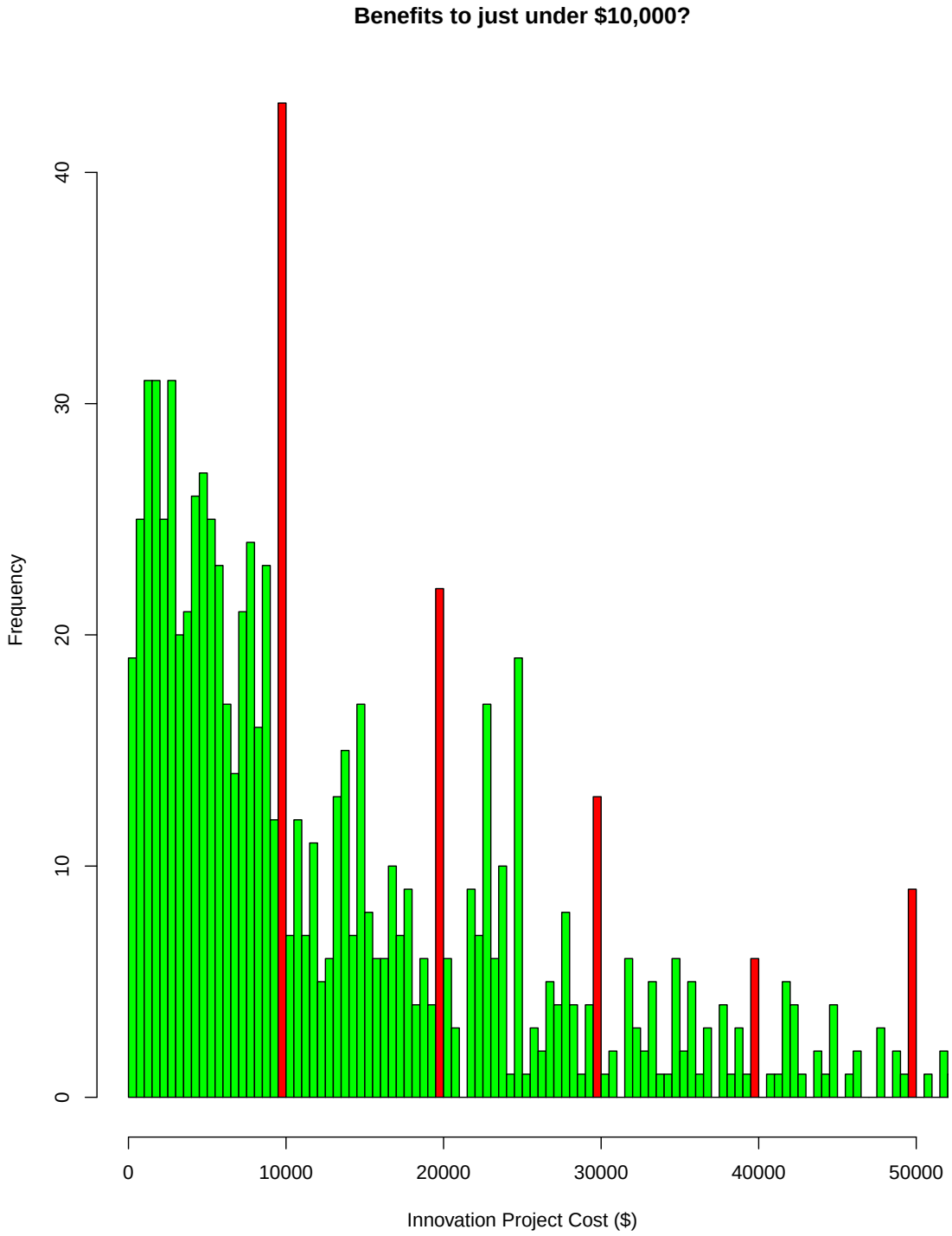

Figure 2-5: Spending Buckets. N = 1200

According to the RAND report, there are a few reoccurring elements that characterize successful innovation in the Air Force. They are led by individuals who hold stubbornly to their vision, and are willing to actively reshape formal structures and regulations. Successful efforts are not fixated on a specific solution, but rather are driven by a problem. Lastly, there is elbow room for mavericks to make moves. Fortunately, the Air Force is stepping towards granting authority to innovation mavericks as manifest in AFWERX and specifically the Air Force Ventures team.

Narrow the Vision and Extend Impact Through SBIR

The SIF is not intended to propel breakthrough technology developments, so holding to a narrow understanding of innovation leads to unmet expectations. Innovation occurs when ideas change how the Air Force operates [9], but the fund largely falls short of this albeit not for lack of vision. The SIF Handbook carefully details how to develop a minimum viable product, engage small businesses, and do market research. In practice, the only examples I came across examples of a minimum viable product or engagement with small businesses emerged at the MAJCOM level, where much more money was involved [10].

This fund excels in empowering those best-acquainted with problems to address them, but the problems being addressed are tactical adjustments. If the Air Force is a system of gears, then the SIF is greasing the gears, not adjusting for a more optimal configuration. An aircraft load-master is intimately familiar that hours of her work-day are spent finagling with a tape measure. She says to herself, "My job is to load the C-17 and I'm using a tape measure. Can we use a laser-profiling system instead?"

While a new sensor for the F-35 remains within the purview of higher decision authorities with broader strategic responsibility, the SIF yields low-hanging improvements such as iPad mounts for aircrews, or oil analyzers for maintenance crews. If a solution is out of reach then the SIF serves as a platform to signal the attention

[9] The SIF Handbook defines innovation the following way: Innovation = Resources + Discipline

[10] Air National Guard provided MVP for beta testing bio-hazard wearable gear for increased mobility.

of heavier funding sources. Last year a squadron invested in Slack to facilitate fluid, mobile communication. If Slack is adopted by the rest of the squadrons in the Wing the following year, then this becomes a clear statement about the efficacy of Slack versus traditional correspondence methods as judged by those using the tech on the ground level. Aside from its direct effects, the SIF empowers invaluable bottom-up signals of the Air Force's operational gaps.

Indirect Benefits Are the Golden Thread

There remain intangible benefits even if the integration of iPads into daily operations falls flat. The SIF exposes airmen to the process and practical difficulties of innovating. When airmen get to test new things, a culture develops that is willing to accept new things. In this way the SIF addresses the innovation *adoption* problem identified by the DIB.

This innovation enterprise is inherently subjective for multiple reasons. First, the goals are difficult to benchmark because there are no performance metrics. It is also not uncommon to see major disparities between high-level and low-level evaluations of a project. In one case, a Wing Commander touted an innovation from a Security Forces Squadron that purchased GoPros to attach to dogs and personnel while on duty. Three levels down the rung, a captain informally commented that the GoPros were only used in the demonstration for the Wing Commander and have not been used since [102].

2.4 Analogy

Finding the audacity to establish a discretionary fund does not guarantee a successful grassroots program, but to glean lessons for how to move forward we turn our attention to BHP, the second largest mining company in the world. The company is organizationally hierarchical, employs 60,000 hands-on workers, and relies on a standardized procedures and regulations to minimize safety risks. The head of innovation, Maria Jose, is now 5 years hence from leading an innovation program that gave dis-

cretionary funding to the miners [70]. She was generous enough to spare an hour of her time to share her thoughts. The following paragraphs synthesize her lessons learned and place them in context of the SIF.

In early iterations of BHP's innovation program, a few lessons came to light. First, the frontline workers were intimately familiar with the limiting factors in daily operations, but they were not accountable for patching the holes in their processes. When the workers were given discretionary innovation money, there was a tendency to fixate on an exciting new toy and fit it to a problem. Things were invented for the fun of playing with them. But as soon as the person who liked the toy left, attention dispersed and the vision for the problem-solution fit dissipated. This is where we end up with iPads and GoPros in desk drawers. In Jose's reflections, the value added for these discretionary funds was empowering a culture of ownership and continuous improvement. In fact, BHP formalized a group called QualityCircles that capitalizes on this by holding contests and rewarding groups with the best solutions. When something is earned, not given, there is greater attachment. The SIF runs the danger of being a given money source, no different than other O&M funds.

The QualityCircles program does not–nor does it aim–to produce breakthrough innovations. Innovation takes times and commitment from higher-level management, and at least a year if new technology is required. A notable technology development that emerged from this grassroots program after a couple years was a giant robotic arm shown in Figure 2-6. The arm provides a safer and more efficient alternative to replacing multi-ton metallic grates. This end-product reflects a significant investment of time and financial resources, and the path to getting there was not managed from low-levels. Higher level management of BHP is responsible for identifying capability gaps in the way of accomplishing the company's five-year plan, which is nestled in the 100 year vision. Although efforts initiated by frontline workers highlight where the capability gaps are, senior management is ultimately responsible for evaluating how much a problem is worth. The long term continuity required to see these projects through rests with senior level management commitment. From here the problems are fielded to small businesses through a public-private open innovation platform called

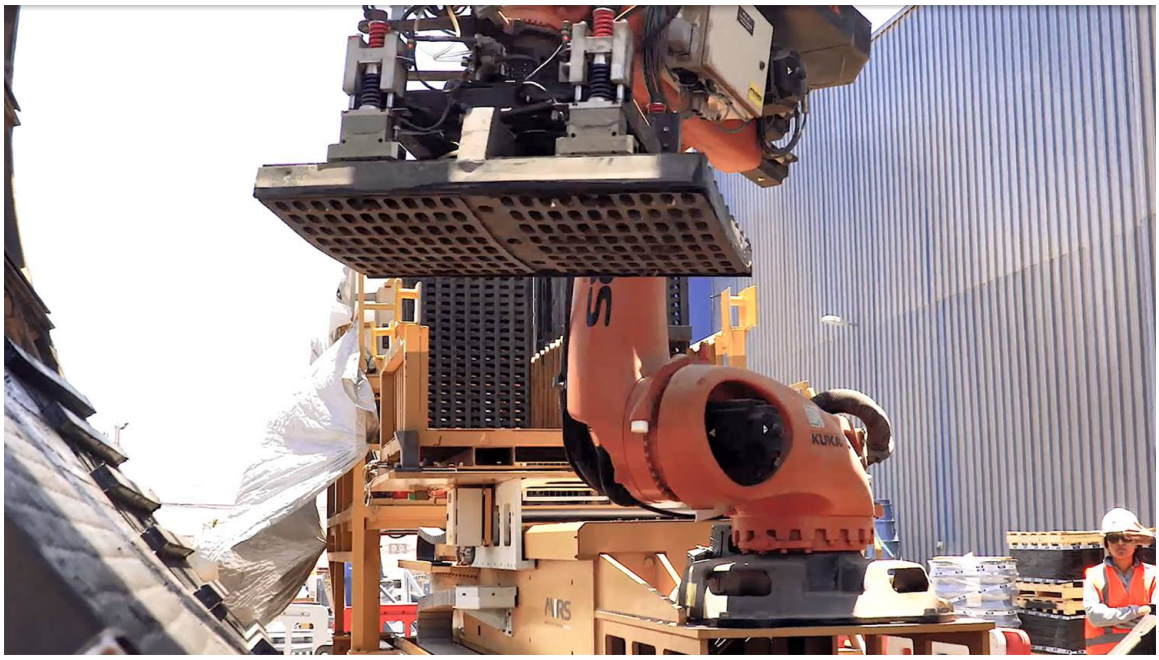

Figure 2-6: Private sector firms rallying around BHP's unique mission set

Expande. This arm is now a key pillar of new technology for the mining industry [18].

In its evolved state, BHP's innovation ecosystem engages frontline workers with QualityCircles through competitions but relies on higher management to prioritize problems and direct heavier funds to innovation projects, which are carried out by a competitive host of small businesses and startups. The distinguishing mark of success here is the ability to prioritize problems based on how much they are worth, if solved. This keeps the focus on the problem, instead of a specific solution. Furthermore, it directs resources smartly across a diverse portfolio of project ideas.

2.5 Recommendations

1. Group projects by mission area on IdeaScale so that they are easily navigable by squadrons with the same technical problems. This also provides an avenue for MAJCOMs or Phase-I SBIR awardees to identify pain points.

2. Improve IdeaScale. The graphical user interface is neither intuitive nor engag-

ing.

3. Learning from BHP's QualityCircles, we should capture the benefits of grassroots innovation through competitions that stimulate a sense of agency, but leave it to higher authorities to filter projects for more intentional development, which has the added benefit of conveying upper-leadership's commitment to pull promising projects through, dismissing cynicism that the SIF is only an innovation charade.

4. Train Airmen to recognize what promising innovation looks like.

5. Provide safety layer to avoid the purchasing of technology black-listed for security vulnerabilities.

2.6 Conclusions

Innovation follows from a disciplined approach. The SIF could extend its immediate benefits by narrowing its focus to updating processes and tools. IdeaScale should be made more navigable for squadrons searching for project ideas. As of now, the platform is not widely used to share and source ideas, and projects are not reported until higher command sends out a tasker to do so. SIF projects are most reflective of modernization efforts.

A shortcoming with the SIF is the absence of a framework to evaluate outcomes. If the goal is to *Start Small*, then *Scale Fast*, upper leadership needs a way to identify promising initiatives. Most helpful would be a metric that signals widespread adoption. For profit-based businesses, return on investment is a sensible metric, but measuring the success of mission-driven organizations is less easily captured in a single outcome metric.

The notion of innovation can be harmful to itself if we start by envisioning the solution as something like iPads, artificial intelligence, or new computers. Interviews with squadron commanders corroborate BHP's identification of solution fixation as the biggest obstacle to grassroots innovation programs [65]. *We need to start with*

the problem, and evaluate the project in how it deals with the problem. It may be unreasonable to gather problems without simultaneously entertaining a solution fit, but if we can suspend our tendency to reach for the iPad we will learn a more practical understanding of innovation. In his book *Innovating*, MIT professor Luis Perez-Breva illuminates what a practical *doing* innovation strategy looks like [84]. With such a practical perspective on what innovation looks like, we will avoid the disenchantment of "innovation" as a hand-waving ideal and be able see the SIF as a means to systematic, exploratory problem-solving. Innovation requires taking risks and absorbing less-than-deal outcomes, but it is important that personnel continue to refine their understanding of what innovation looks like.

The greatest benefits of the fund are contingent upon ample patience to allow this program to evolve over a few iterations. It should also not be overlooked that there is value in the shock itself, as it stimulates conversation. From an analytical standpoint, it is difficult to assess the worthiness of the purchases because performance metrics are undefined. One metric that would make sense to consider is the rate of interactions on IdeaScale because the whole grassroots approach relies on collaboration and cross-unit communication. If the SIF is to justify its investments, then we need to move towards a systematic evaluation schema. More generally, the SIF should not be expected to generate new technologies, which should be left to higher leadership, but should be leveraged to highlight problem areas for Phase-I SBIR special topic awardees.

In some cases, we may not recognize the far-reaching implications of a change until we start moving things around. General Goldfein's bold move of pushing discretionary funds to unprecedented levels is laudable because it is a shock to the system. We should not be surprised to see disparity in project performance as the kinks are identified and the various actors recognize the roles best suited to them.

The direct effects of this fund are incremental, but its greater potential lies in how it empowers ground-level technicians to highlight glaring problems of current practices. Implementing incremental innovation in large organizations benefits from a broad vision, loosely defined boundaries, and time to reveal promising trends. In this light, the SIF positions the Air Force to be more responsive to operational capability

and efficiency gaps with the further potential to engage SBIR's new class of innovative companies for development efforts.

2.7 Contributions

1. Set forth two dimensions along which to view innovation in the Air Force, distinguishing between the impact and the process
2. Captured the expressed intent of the SIF
3. Extracted four primary modes of spending, and illuminated with examples
4. Conceptualized and empirically visualized what the money was spent on and why the money was spent
5. Revealed a trend in spending just under multiples of $10,000
6. Compared the SIF to a relevant industry success
7. Recommended actionable steps forward

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Chapter 3

SBIR and AFWERX Adaptations

3.1 Part 1: SBIR is the Catalyst for an Agile Defense Base

The first part of this chapter outlines the intent, structure, assumptions, and controversies of SBIR in the Air Force. The second half expounds the dynamic nature of SBIR under AFWERX in light of the overarching goal of reaching a more expansive group of innovative small businesses.

3.1.1 Small Businesses are Innovators

MIT President Jerome Wiesner proclaimed that Vannevar Bush's "most significant innovation was the plan by which, instead of building large government laboratories, contracts were made with universities and industrial laboratories" [62]. Today, a bent towards open innovation places small businesses in an increasingly crucial role as large firms look beyond internal R&D branches and seek collaborations with small businesses and universities [76].

Direct government investment in small business research, then, is a promising avenue towards an agile defense base. As incubators for novel technologies flush with support from private equity, startups and small businesses are an integral link in the open innovation architecture. Yet, exactly how the government should support small

businesses is an open question. At stake are both the readiness of the U.S. military and economic prosperity.

Small businesses are long attributed with disproportionate contributions to novel technologies and job creation [23, 59, 27]. While World War II forged support for direct investment in the private sector generally, the 1970s brought congressional support for more pointed investment in small businesses. Spurred by concern the U.S was losing its competitive edge in an era of globalization, Roland Tibbetts set in motion the predecessor to the modern SBIR program [7]. Today, small business is referred to as the "backbone of the U.S. economy" [50, 10]. As of 2016, a survey based study from Babson College found that small businesses employ nearly half of the workforce and account for more than 60% of the private sector's net new jobs [28]. More optimistically, the Small Business Administration (SBA) puts the proportion of net new jobs from small businesses at 75% [6].

New businesses have a burden of novelty and so are more willing to take risks. They execute ideas more quickly and pivot more swiftly than enterprise level companies. Dr. Roper, the Assistant Secretary for Air Force Acquisition refers to small businesses as the "initiators, catalysts and medium for wider technical change" [24]. Larger companies rely on established product lines and may be legally answerable to shareholders expecting consistent returns. Even today's tech giants emerged from humble beginnings. Google and Facebook were born out of the aspirations of university students hedging their bets on unrealized ideas–improving web searches through better algorithms in one case and popularizing virtual networking in the other. Even after growing to massively influential companies, iconic tech companies look back to promising startups to sustain their leading edge. Exemplifying this trend are Facebook's acquisitions of Instagram, SnapChat and WhatsApp.

That nascent business ventures are cash-strapped is one compelling argument for public support. Nine in ten startups fail [83], and private equity sources tend to bias towards short-term, less risky, software-based enterprises with more apparent market demand [86]. Fortunately the government has the bandwidth to pursue riskier, exploratory research efforts neglected by other equity sources.

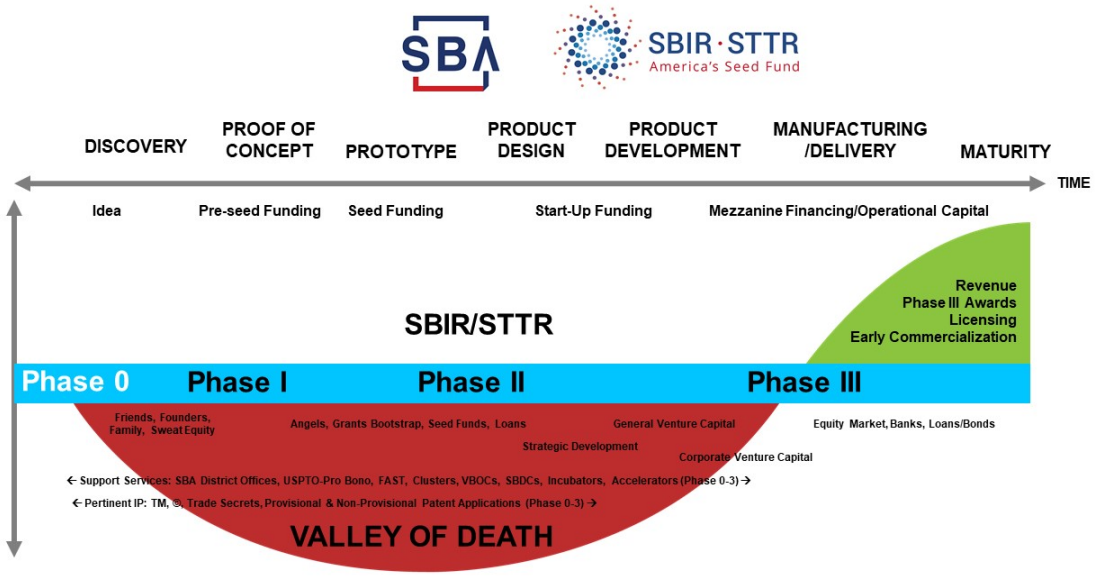


Figure 3-1: Source: SBA.gov.

To explain where the SBIR fits alongside other equity sources the SBA generated Figure 3-1, which depicts the Valley of Death facing small businesses.

3.1.2 SBIR Targets Innovative Small Businesses Facing the Valley of Death

Under statutory mandate each federal agency with an R&D budget greater than $100M in R&D is to allocate 3.2% of these funds to small businesses. This allotment makes SBIR the predominant source of government funding for early stage ventures [26]. According to the SBA, the mission of the SBIR program is "to support scientific excellence and technological innovation through the investment of Federal research funds in critical American priorities to build a strong national economy" [6]. The goals are four-fold: (1) stimulate technological innovation, (2) meet federal research and development needs, (3) foster and encourage participation in innovation and entrepreneurship by women and socially or economically disadvantage person, and (4) increase private-sector commercialization of innovations derived from Federal research and development funding.

More concisely the purpose of SBIR is to fill the funding gap left by other funding sources. As emphasized by a Pentagon official in an op-ed, SBIR has the opportunity to invest in geographic regions passed over by private equity [30]. More generally, there is opportunity to rally participation from previously neglected groups.

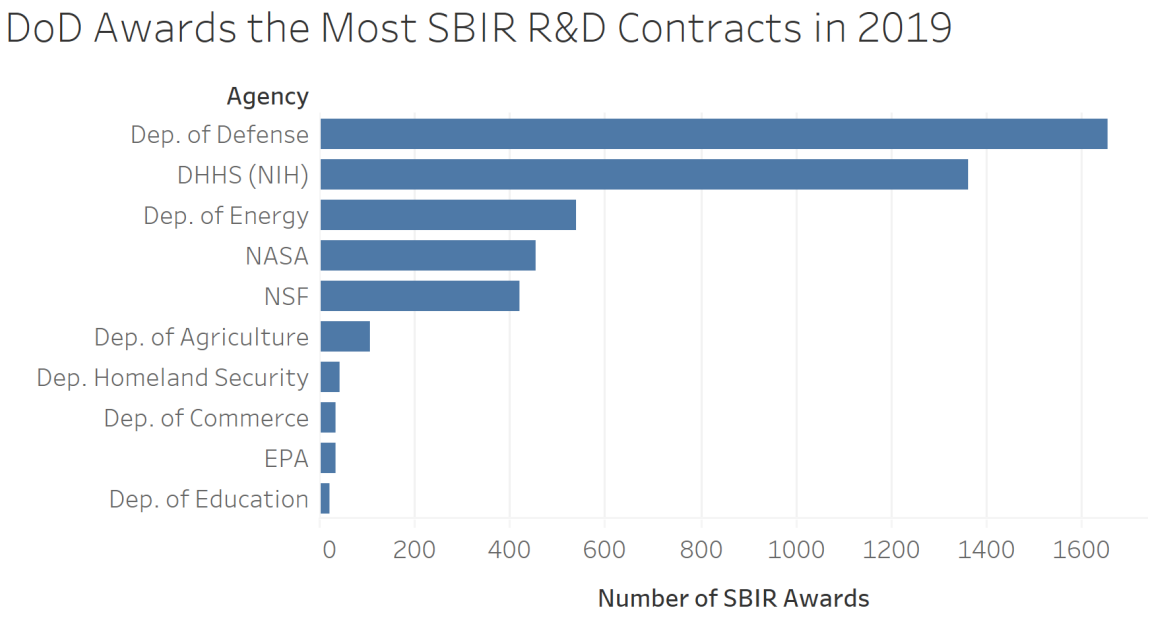
Across the eleven federal agencies participating in the SBIR program, the DoD accounts for nearly half of SBIR spending. While the DoD awards the majority of the government's SBIR awards, the Air Force leads the DoD. Figure 3-2 demonstrates this.

3.1.3 STTR: The Little Sibling

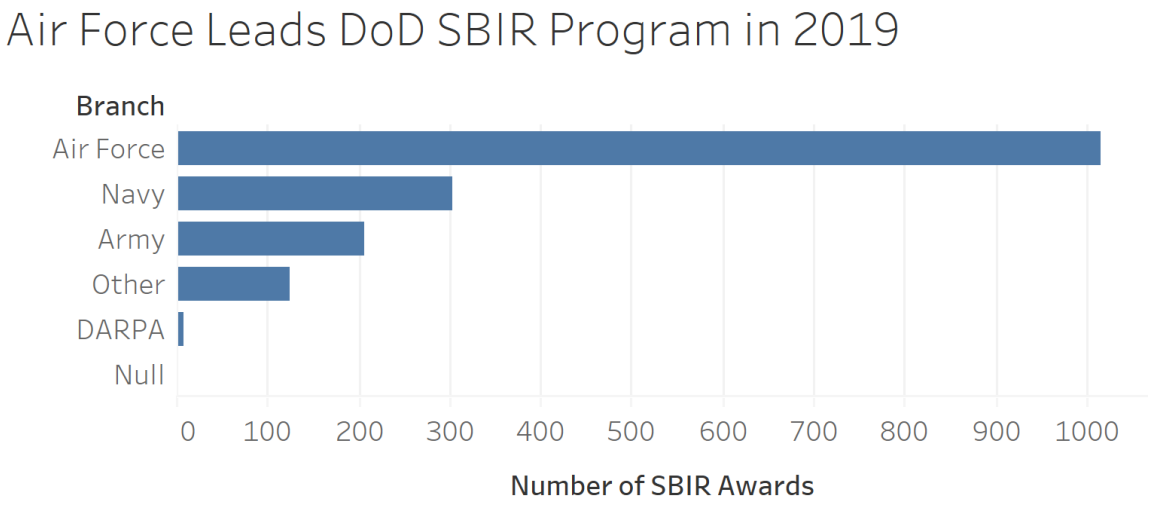
Nonprofit research laboratories are instrumental in developing cutting edge technology, and the entrepreneurial outlook of small businesses are well suited to transfer theoretical work to practical applications. This insight motivates the Small Business Technology Transfer (STTR) program, which requires a formal collaboration with a research institution. Five federal agencies contribute 0.45% of their extramural R&D to STTR. Although SBIR applicants may subcontract universities, the STTR program explicitly requires partnership with a research institute. Higher coordination costs associated with STTR, however, make them less popular among small businesses according to informal communications with Air Force officials. Figure 3-3 compares the annual amount awarded between SBIR and STTR. Although academic work often addresses both SBIR and STTR together, this work focuses on the Air Force SBIR program.

3.1.4 Structure of SBIR

The governing policy directive for SBIR published by the SBA grants federal agencies flexibility in executing SBIR. This section however describes the Air Force SBIR program.



(a) DoD Leads Government Agencies



(b) Air Force Leads DoD

Figure 3-2: Note: Each agency and branch may vary the proportion of Phase-I to Phase-II awards, as well as the award size.

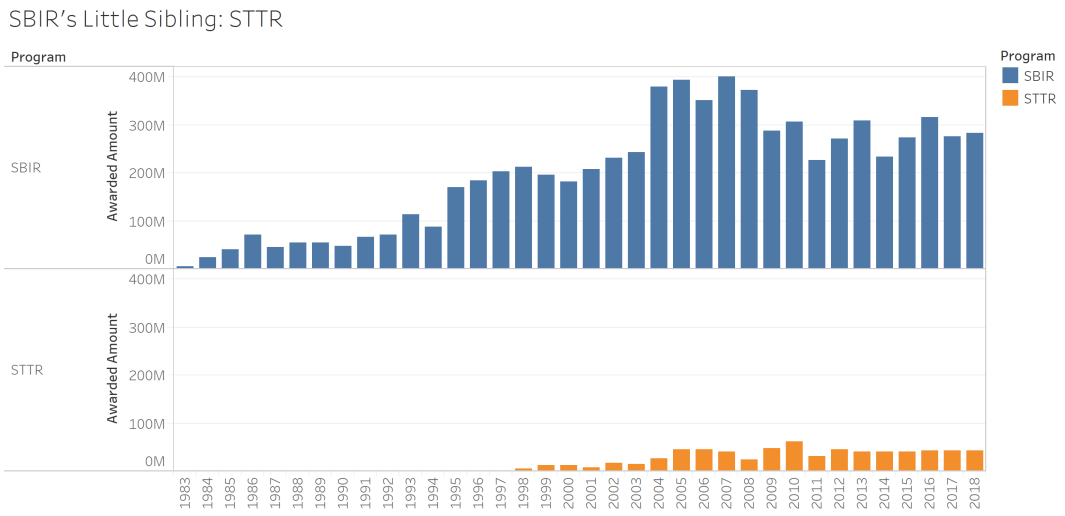


Figure 3-3: Air Force SBIR and STTR Awards from 1983-2018. Source: SBA.gov

Three Phases

Common to all agencies, SBIR has three phases. A Phase-I contract is limited to $150,000 for a nine month performance period. The goal is to establish the credibility of the small business as a working partner along with the technical merit, feasibility, and commercial potential of the specific proposed R&D effort. Funds may be applied to activities other than R&D, but contract proposals include an itemized spending plan.

A Phase-II SBIR award is worth up to $750,000 for two years and is distributed across key milestones with the primary checkpoint being a working prototype. To be eligible for a Phase-II award companies must be Phase-I awardees [1]. Per the SBA website, Phase-II proposals are evaluated for the technical merit and commercial potential of the proposed project.

The goal of SBIR is commercialization. Getting to commercialization in an open innovation architecture involves multiple rounds of funding from various sources, and Phase-III seeks to spur this transition by requiring external financing. Although SBIR does not fund post Phase-II efforts, previous award status satisfies the legal requirement for competitive acquisitions so that companies can sell their product to other

[1] As of the beginning of 2019, an exception under AFWERX special topics allow for Direct to Phase II

government end-users without having to go through another drawn out solicitation process.

From Problem Identification to Contract

Moving from the identification of a capability gap to contract takes nine to twelve months, according to Matthew Scott, Managing Director of AFWERX Austin [71]. The process starts with writing a topic, or a specification of the need. For example, a topic title such as *Cost Efficient Testing of Space Microelectronics Using Wireless Technology* would be accompanied by a 500-word description of design requirements written by scientists from Air Force Research Laboratory. After identifying a capability gap, proposals are solicited through a Broad Agency Announcement (BAA), satisfying legal stipulations for competition.

There are three solicitation periods per year. Barring any disqualifications, proposals are scored on the following three criteria. Proposals with a cumulative score above a threshold are awarded [69]:

- Technical Merit: The soundness, technical merit, and innovation of the proposed approach and its incremental progress toward topic or subtopic solution

- Potential for Commercial Application: The potential, given matching funding secured from outside investor(s), for commercialization, Government or private sector, and the benefits expected to accrue from this commercialization

- Qualifications of the Principal Investigator (and Team): The qualifications of the proposed principal investigators, supporting staff, and consultants. Qualifications include not only the ability to perform the research and development but also the ability to commercialize the results

For consistency, each criteria is scored by a single evaluator. After evaluations the selected companies are passed on to contracting. From topic origination to contract award takes nine to twelve months, but latency can exceed three years [71].

Monetary and Non-monetary Incentives

As pointed out by Ryan Erickson, the head of operations at AFWERX Austin, the real incentive for companies is not the initial award amount but the opportunity for follow-on partnerships with other DoD end-users [71]. That Phase-I awards are rather small reflects the presumption that these awards are meant to only temporarily sustain companies as they develop their technology. Firms may receive multiple awards for different projects, but are limited to one application per solicitation round.

Proposals lay out an itemized budget request, but there is no way to enforce compliance after funds are awarded. Instituted to audit the financial records of government contract awardees, the Defense Contract Audit Agency (DCAA) serves as a stamp of approval, though they do not have bandwidth to verify all applicants. According to the data used in chapter four, only 20% of applicants to Air Force SBIR from 2018 to 2019 had a DCAA record.

Government money is "colored", that is, it is binned for specific purposes before it is given to the service branches. SBIR money is colored for Research Development Test and Evaluation (RDT&E), and so difficulties arise when SBIR funds are directed towards commercially available technologies.

3.2 Points of Controversy

"One of the great mistakes is to judge policies and programs by their intentions rather than their results." –Milton Friedman

The benefits of SBIR have been scrutinized on more than one account. In fact, there is a sunset provision that defaults the SBIR program to expire unless extended by Congress. According to SBA, this provision took effect in 2009, although a serious of continuing resolutions sustained the program until it was officially reauthorized in 2011 [7]. What follows is an overview of the primary points of contention.

3.2.1 Measuring Outcomes

Commercialization

The goal of SBIR is commercialization, but commercialization is difficult to measure and does not capture the benefits of early stage R&D within an open innovation ecosystem. To start, if SBIR funds projects that otherwise go unfunded, they are likely riskier and bound to longer development timelines. Furthermore, commercialization is an inherently unresponsive metric because taking an idea from inception to product line takes years. Numbers that the Air Force do collect rely on a contractual requirement that companies self-report sales for five years following SBIR work. Even if the Air Force had perfect information on the sales of SBIR awardees, it would overlook the subtle spillovers to other companies. And even if the Air Force tracked formal knowledge spillovers through acquisitions and license transfers, informal means are increasingly prevalent in the open innovation paradigm. As a result, it is difficult to trace the impacts of early stage R&D funds.

Despite this, notable efforts have aimed to estimate commercialization rates, the probability of commercialization, and the treatment effect of an award on downstream commercialization. A thesis by Captain Rask from RAND puts commercialization at 7.6% for Air Force SBIR [100]. As Rask mentions, there are two reasons this estimate may be overbiased. First, companies may be more inclined to report if they have good news to share. Second, dissolved companies will not show up in survey responses.

In a 2010 journal article, Albert Link and John Scott predict the probability of commercialization of a SBIR funded project conditioned on certain characteristics. In other words, this effort estimates the a priori uncertainty that a project will result in commercialization [68]. Their results propose a 45% commercialization rate, much higher than Captain Rask's estimate. This model relies on relatively few observations spread across many variables and there are no robustness checks for strong a priori assumptions on the distributions of the features.

Instead of predicting the probability of commercialization, a dissertation from RAND judges the treatment effect of an SBIR award on downstream government

commercialization to be $370,000 [45].

Ultimately, attempts to tie commercial sales back to SBIR contracts are frustrated by drawn-out, circuitous development cycles and a reliance on self-reported earnings. There have, however, been attempts to evaluate SBIR apart from commercialization.

A 1993 amendment to the statutory mandate governing SBIR codified a requirement for better performance metrics. One attempt to address this is the Commercialization Achievement Index (CAI), which quantifies the past performance of companies relative to other awardees in the same time period. The reception of the CAI has been less than promising. In 2005 the Office of Management and Budget's (OMB) mandated review of DoD SBIR classified the entire DoD SBIR program as "results not demonstrated", primarily because the OMB deems the CAI an inadequate performance metric [45].

Economic Impact

Instead of trying to pin down commercialization outcomes, some efforts estimate downstream economic impacts. In January of 2019, a report based on the economic IMPLAN model claimed a return on investment of 21:1 for Air Force SBIR/STTR between 1985 to 2018. Inputs to the IMPLAN model were generated by surveys that achieved 96% response rate for 16,000 companies [99]. It is possible however that survey bias, disregard for counterfactuals and inflated multipliers contributed to an overly optimistic analysis. It may also be worth noting that the report was contracted by the Air Force and the authors' salaries rely on SBIR funds.

Dealing with Uncertainty

Policy analysis describes scientific evaluations of the impacts of past policies and predictions of future outcomes. That previously discussed estimates of commercialization differ by a factor of six speaks to the fragility propagated by unsupported assumptions and limited data.

Favorable assumptions and crafted slices of data can be exploited to present a certain set of results, even in the absence of blatant unethical conduct such as generating

fake data. In a journal entry for the National Academy of Sciences, Charles Manski writes about the features of large government organizations that lend themselves to misaligned incentives.

> Finally, we mention a serious organizational difficulty in discussing and criticizing statistics. These are virtually always produced by large organizations, government or private; and these organizations are frequently mutually dependent upon each other in order to function normally. Often one office cannot publicly raise questions about the work of another, even when it suspects the quality of the work, since this might adversely affect bureaucratic-diplomatic relations between the two and the flow of information from one office to another might be hampered. A marked esprit de corps prevails. All offices must try to impress the public with the quality of their work. Should too many doubts be raised, financial support from Congress or other sources may not be forthcoming. More than once has it happened that Congressional appropriations were endangered when it was suspected that government statistics might not be 100%.

Maligned incentives aside, commercialization is not a reasonable metric of performance for SBIR because of latency and diffuse avenues of impact.

3.2.2 Problems with Topic Generation

In addition to being slow, the traditional process of generating topics hosts its own set of maligned incentives. According to Matthew Scott, topic generation "involves considerable coordination and time" [71]. This is because acquisitions are legally required to be competitive though in some cases topics are reverse-engineered to fit the capabilities of a specific company. A high visibility showcase of this dynamic occurred in 2019 when IBM and Oracle accused the DoD of drafting a $10B cloud computing topic unfairly biased towards Amazon's infrastructure [4]. Additionally, the one-to-one matching scheme places a high burden on the Air Force to identify its most pressing capability gaps.

3.2.3 Does SBIR Crowd out other Equity Sources?

The underlying justification for investing public dollars in private companies is that emerging businesses do not internalize the social benefits of their development efforts. As a corollary, if other equity sources pass up these investment opportunities, the government should absorb the risk of early ventures. It is not immediately obvious, however, what the counterfactual funding scenarios are for companies who do receive SBIR awards. Josh Lerner from Harvard argues that R&D subsidy programs crowd out private investment and allocate funds inefficiently [67]. Against the background of an expanding and diversifying equity pool [86], the possibility of unnecessarily displacing private investment is worth consideration.

If SBIR does displace other equity sources, how might companies fare differently with non-dilutive government funding? Through a matching design that leverages machine learning to generate propensity scores, Jason Rathje provides evidence that SBIR improves short term survival while hampering long term growth [33].

3.2.4 Static Pool of Awardees

In practice the SBIR program generates a back-eddy of companies surviving from SBIR awards while remaining inaccessible to innovative small businesses lacking the time or administrative familiarity to work with the government [71]. According to award records I pulled from SBA, 79.6% of Air Force SBIR contracts between 1983 and 2017 went to previous award winners. Ideally, companies find product traction with government end-users or private consumers and do not return to SBIR for additional rounds of funding. Not only does this high return rate imply that many awardees are failing to develop useful technologies, but it shows that previous awardees are likely to be awarded again. Institutional concern that SBIR repeatedly supports the same group of static companies is reflected in new guidelines that require Phase-I awardees meet benchmarks demonstrating progress towards commercialization [91].

Administrative Barriers

One explanation for the concentration of awards is that previous awardees are attuned to administrative overhead. First, to be eligible to work with the government, companies need to be verified by the System for Award Management and register for a Dun & Bradstreet Number (DUNS). After being verified and registered, companies face an application process that takes full times employees a month to put together [61]. Even though SBIR funding is non-diluting and allows companies to maintain intellectual property rights, the venture capital community generally advises startups against working with the government due to slow award timelines and administrative overhead [33].

Lack of Awareness

When I asked Mr. Lee, the Program Coordinator for Air Force Office of Scientific Research, what keeps companies from applying to SBIR, he first mentioned awareness [78]. Interviews with AFWERX Austin leadership reinforced that many companies are not aware of SBIR [71]. If there is a stigma that government is slow and arduous to work with among the communities mentoring startups, then it is not surprising that government contracts are not considered.

Six Death Knells

According to the Director of AFWERX, Dr. Brian "Beam" Maue, there are six "Death Knells" that explain why companies choose not to work with the government [73].

1. Complexity – Navigating government websites is often fraught with security warnings, broken links, or misplaced menu items. Such glitches reinforce sentiments that working with the government is less than seamless.

2. Timelines – Nascent startups do not have established cash flows and hence are subject to short "runways". The long timelines under traditional SBIR compel investors to advise startups to look elsewhere, or wait until they have enough cash flow to survive unforeseen delays.

3. Requirements – The traditional topic generation procedure places the onus on the Air Force to outline a problem and specify the technical details of the solution. This cuts out the innovative approaches that startups may be able to offer.

4. Access – The innovation ecosystem is dizzying. If a company does want to work with the DoD, it has to sort through a dynamic landscape of programs with varying requirements, award sizes, and follow-on opportunities. What's more, Dr. Maue points out, "the 'customer' (who is responsible for acquiring the solution) is often different from the 'User' (who stands to operationally benefit from the solution)" [73]. The scientists and program managers writing topics and allocating funds are not the individuals working with the technology.

5. Transition – In an interview I conducted with Matthew Scott, Director of AFW-ERX Austin, he said that the initial award amount is not the end, but seen as a means to getting access to a larger DoD market [71]. Companies want to know that the cash flow may follow initial Phase-I awards.

6. Sentiment – In Dr. Maue's words, "The anachronistic approach of relying on impersonal forms and processes to attract innovators will not be as effective as adding a human touch".

Smaller Startups are most Vulnerable to these Barriers

For the emerging tech startups with a short runway that do come across SBIR, a 30% award rate is hardly comforting [78], especially if the application process is time-intensive. Without previous experience, navigating the verification and application processes is daunting and may compel nascent companies to defer to other funding sources even if it means trading equity.

3.2.5 What Changes are Being Made to Address these Controversies?

Up to this point we have seen how a surge in private sector R&D prompted the DoD to focus on reimagining its acquisition pathways through previously disengaged businesses. Then we identified the SBIR program as a prime candidate to establish a dynamic defense base because it targets small businesses, increasingly the lynchpin in the open innovation paradigm. Unfortunately in practice the SBIR program is engaging a closed, static group of companies, presumably due to administrative barriers and lack of awareness. Part two of this chapter introduces the changes AFWERX is introducing to attract the previously disengaged, yet innovative and promising companies.

3.3 Part Two: AFWERX Reimagines SBIR

Instituted in July of 2017 by then-Secretary Wilson to catalyze innovation in the Air Force, AFWERX has since taken steps to open up the Air Force innovation ecosystem. This strategy has taken the form of joint military-civilian events in addition to stark adaptations to its existing SBIR program. Instead of funneling small businesses into the traditional mold for defense contractors, these reform efforts seek to make the Air Force an extension of existing innovation ecosystems, replete with technology accelerators, pitch days, and shark tanks. Two months after the instantiation of AFWERX, Air Force visionary Captain Chris Benson stood at the inaugural Air Force Technology Accelerator event: "And now, here we are, and we're hoping that we can build trust in the startup ecosystem to tap into their creativity without killing them, or making defense contractors out of them" [82]. In an increasingly dual-use world, companies can leverage SBIR to develop their technology without being beholden to defense funds.

An open innovation system is one where DoD is one of many partners for cash-strapped innovative businesses. Colonel Jason Brown at the Pentagon wrote an op-ed

titled *To Compete with China, Make the Military a Venture Capital Powerhouse* [30]. Dr. Roper mirrors this sentiment: "[The goal is to] catalyze the commercial market by bringing our military market to bear...We're going to be part of the global tech ecosystem." [63]. The rest of the chapter outlines the changes and events introduced by AFWERX, setting up chapter four to evaluate the success of these changes.

3.3.1 Spark System, Challenges, and Tech Accelerator

The AFWERX Spark system looks internally to encourage participation from ground level operators to highlight problem areas and propose solutions, while Challenges and Colliders offer platforms to bring those problems to industry. More intentional relationships with startups are cultivated within the Air Force Technology Accelerator, which is now mentoring its third cohort.

Spark Cell

Spark cells are local to Air Force facilities and serve as a hub for Airmen to test and refine their idea, get information for next steps and benefit from crowd-sourced experience. Introduced alongside the SIF in 2018, these Spark Cells foster grass-roots innovation at the base level.

Spark Tank

AFWERX's vision for the Spark system extends beyond empowering units to address their own problems; it seeks to scale the best solutions and recognize the intrapreneurial spirit in front of top-brass. Modeled after the Shark Tank TV-show and sponsored by the Secretary and Chief of Staff of the Air Force, the annual Spark Tank competition is a high energy capstone event that showcases top Airmen initiatives. The winning proposal at the inaugural Spark Tank competition in February of 2018 was a remodeled resting platform for KC-135 boom instructors that alleviates back and neck pain [96].

Spark Collider Events

If Spark Cells and the Shark Tank competition target the ingenuity of Airmen, then Collider events aim to bring small businesses to the table. In practice, Collider events are a great way for Phase-I awardees to find Air Force stakeholders interested in their technology. The first Collider event in August of 2019 brought together 150 Airmen representing 50 bases and 200 entrepreneurs representing 100 Phase-I awardees. At this event, Alex Brickner, chief product officer of SimpleSense, commented to a reporter that the Spark Collider is a great opportunity to talk to warfighters and stakeholders directly: "Usually, a private entity has to jump through a lot of hoops in order to talk to a single person, so having 40 or so different program offices is a really great opportunity" [1].

Challenges and Fusion Events

A core tenant of the open innovation paradigm is a high valuation of previously neglected groups. As AFWERX's CEO Dr. Maue puts it, "By bringing together Airmen, industry professionals, small businesses, university students, and subject matter experts from various environments we enrich our understanding of what's possible" [73]. AFWERX Challenges widen the aperture beyond Airmen and small businesses, which are the target groups of Spark Cells and the Spark Tank competition. AFWERX Challenges are open to anyone and are focused on a specific problem. Over 100 proposals were submitted to the USAF Fixed Wing Helmet Challenge in November 2018 [52].

The annual AFWERX Fusion Xperience is a scaled up version of a Challenge. The two-day event takes place in Las Vegas where a down selected group of companies presents their solutions to military leaders and private sector investors. The inaugural June of 2018 event focused on Site Security. The sold-out 2019 event centered around Multi-Domain Operations, which describes the DoD's intention to leverage AI to facilitate operations across a suite of platforms in dynamic threat environments [19]. The 2020 schedule surrounds the Base of the Future.

Tech Accelerator

In a more pointed form of mentorship, AFWERX partnered with the Techstars Technology Accelerator to incubate promising startups with dual-use technology. The first two cohorts of 2018 and 2019 have shown a greater than 10x growth in follow-on investments by the private sector and government since AFWERX first invested in their incubation period in the Technology Accelerator [73]. Perhaps most importantly, although implicit, is the message that the Air Force can work with startups without cornering them into being defense contractors.

3.3.2 Changes to SBIR

A guiding principle for AFWERX from its CEO, Dr. Brian Maue:

> What we found was that when you stop to see things from the other person's perspective and begin to eliminate, or at least minimize, roadblocks for them, the path to working together seems to smooth itself out [73]

AFWERX's reforms of the forty year old SBIR problem owe themselves to a group of visionaries fortunate to have had the top-cover that Dr. Eric Schmidt described in his testimony to the House Armed Services Committee as being the difference between stagnation and innovation [92]. Starting in June of 2018 with the introduction of Special Topics, AFWERX has stripped the application process, shifted the onus of problem identification to companies through Open Topics, attracted external finance, and introduced a new class of longer-term $15M contracts among other changes.

First: What is a Topic?

A topic can be understood as an application channel. It is specified by a topic owner (the funder), a problem statement, an award size limit, an evaluation process, financial matching possibilities, and other stipulations such as prerequisites for eligibility. The conventional application channel was outlined in the preceding pages. The following sections explain the new application channels available after AFWERX's changes.

Special Topics

Special Topics is an umbrella term to describe topics that have shortened technical durations, reduced reporting requirements, and smaller award amounts. Specifically, the 20-page technical report of the conventional process is replaced with a 5-page white paper and a 10-page slide deck. And instead of $150,000 for a Phase-I award, Special Topics are limited to either $75,000 or $50,000 depending on other factors discussed later. The following sections describe other changes that have layered on top of Special Topics.

When Special Topics were introduced in June of 2018 alongside their conventional counterparts, they accounted for a small portion of SBIR awards. Over the last two years Special Topics and its variants have grown to command the majority of Air Force SBIR awards. Figure 3-4 showcases the momentum of Special Topics as captured by the comparison of awards allocated through Special Topics to those allocated through the conventional process.

Open Topics

Open Topics address at least three of the “six death knells” that prevent companies from applying to SBIR: timeline, requirements, and access. First, all Open Topics are Special Topics–they have the stripped application and expedited award timeline–so companies spend less time waiting.

Second, whereas a traditional SBIR topic might specify a need, such as "Rapid Manufacturing of Anodes for Electroplating," the Open Topic is an open call, setting aside Air Force preconceived technical requirements and opening the market to include all Air Force stakeholders.

That is, the Open Topic flips the traditional contracting paradigm from a demand-pull to a tech-push. In fact, Phase I awards are intended to support customer discovery for Phase-II prototyping, something that companies usually finance themselves. The customer, in this context, might be a security forces squadron who is responsible for base security and needs automated border surveillance.

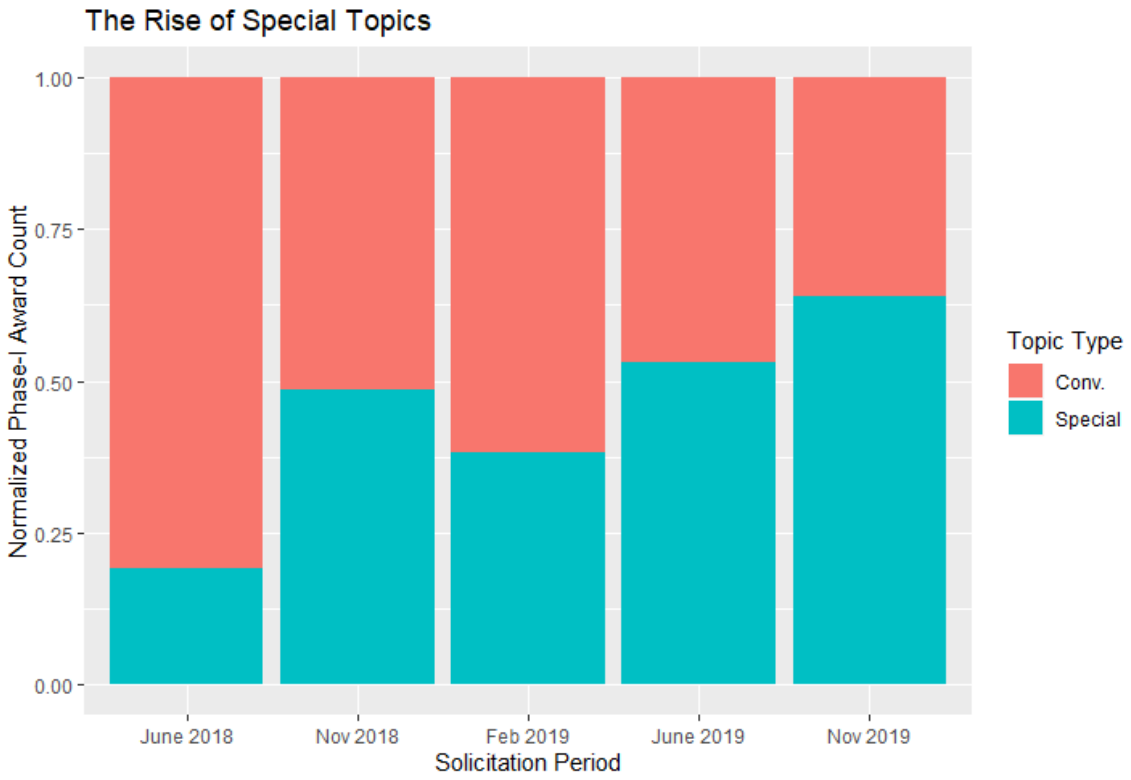


Figure 3-4: With time a higher proportion of Phase-I's are awarded through Special Topics. The proportion of Phase-I's were used because of missing solicitation periods for conventional Phase-II awards. Data Source: AFWERX

The published title for the Open Topics highlights the emphasis on adapting non-defense commercial solutions: *Open Call for Innovative Defense-Related Dual-Purpose Technologies/Solutions with a Clear Air Force Stakeholder Need*. According to the data collected for Chapter 4, from the beginning of Special Topics through 2019, 67% of Special Topic awards were Open.

Pitch Days

Pitch days aggressively address the death knell of long *timelines* that are believed to drive fledgling companies away. In a matter of minutes, AFWERX awarded 51 contracts with a total initial value of $8.75 million at the inaugural Air Force Pitch Day event held in New York City on March 6th and 7th 2019 [97]. Since then, AFWERX has hosted at least ten more Pitch Days with topic focuses such as simulators, space, airborne communications, and hypersonics. While not explicitly Open Topics, these

application channels present a broad focus area and give companies agency in finding a fit for their technology. Around 13% of Special Topic awards through 2019 have been won through Pitch Days.

RAPID: Matching Funds

Attentive to the legitimate fears that partnering with the DoD stunts growth [33] and forces companies into the defense contractor mold, AFWERX explicitly incentivizes applicants to find joint investment partners in venture capital or else in other arms of government. This verifies external demand for the proposed technology to help pull it forwards. First introduced in January of 2019 for Phase-II applicants, RAPID designates an application channel with a 4:1 matching ratio for government investors and 1:1 matching ratio for private investors up to $1.5M in SBIR award money (e.g. $375,000 Government + $1.5M SBIR, or, $1.5M private + $1.5M SBIR). The ratio for SBIR to government matching changed to 2:1 in November 2019. Ultimately, matching funds is a step towards aligning Air Force R&D alongside private sector demand and showing that the Air Force intends to work in synergy with a broader innovation ecosystem. According to my collected data, which I believe to be a slight underestimate, 3% of Special Topic awards had matching funds through the end of 2019.

Direct to Phase-II

The conventional process requires Phase-II applicants to have already gone through Phase-I, but AFWERX introduced a provision in the first solicitation of 2019 to allow companies to apply directly to Phase-II.

CSO: Under New Acquisition Authority

The government introduced Commercial Solutions Opening (CSO) to grant more flexibility for agencies to procure commercial technologies. Unlike Broad Agency Announcements (BAA) which are restricted to basic and applied research and that portion of development not related to a specific system or hardware program [15],

CSO allows technology that is directly relevant to a specific program to be acquired. They are considered competitive for the purposes of 10 U.S.C. chapter 127 and FAR 6.102 [15].

In practice, CSO was a workaround for AFWERX to combine SIF and SBIR funds [71], because CSO is colored for Operations and Management (O&M) while traditional SBIR is colored for RDT&E. The shift to CSO in the last solicitation period of 2019 formalizes what was already implicit in Open Topic before–that the focus is less on basic research and more on tech that already has market traction.

Joint Partners

In the first solicitation of 2020, the Air Force SBIR topics under AFWERX were solicited alongside joint partners to include: US Army, Special Operations Command, National Security Innovation Network, National Geospatial-Intelligence Agency, and Defense Microelectronics Activity [21]. In pulling together more funding sources, AFWERX is presenting an expansive market to prospective companies.

STRATFI

AFWERX's biggest bets are directed through Air Force Venture's Strategic Financing (STRATFI) program, which in 2020 is slated to push $1B to some 30 to 40 "game-changing" Phase-II awardees in hopes of vaulting them over the infamous Valley of Death [63]. This amount includes $100+ million in SBIR funds, $100+ million in Air Force funding and $350+ million in private investment. Roper said he believes future rounds of funding will be bigger [63].

3.3.3 Chapter Summary

This chapter presented the state of the SBIR program in Part 1, following up an overview of criticisms with how AFWERX responded through collaborative events and a series of changes to SBIR. Chapter four investigates whether AFWERX's SBIR Special Topics caused a new type of company to apply, and if so, whether those types

of companies were more successful with Special Topics than with conventional topics.

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Chapter 4

Econometric Analysis

4.1 Motivating Questions

The past chapter explained AFWERX's SBIR reforms in the context of an emerging ecosystem of Air Force sponsored tech accelerators, industry events, and grassroots engagement. Given these changes, two questions naturally emerge:

1. Did the application channels introduced by AFWERX compel new kinds of companies to apply? Specifically, were they smaller? Did they have financial backing? Have they been previously awarded?

2. If Special topics did attract a new kind of company, did these new kinds companies have a higher chance of success under the new special topics?

4.2 Introduction

In 2017 the Secretary of the Air Force and the Chief of Staff established AFWERX with the goal of bringing Air Force operations in line with state-of-the-art praxis and technologies against the backdrop of a DoD wide push for more agile acquisition pathways. Since its inception, AFWERX has engaged previously untapped innovation hubs, building out an open network to inspire, fund, and facilitate mission-driven technology development.

That small companies contribute disproportionately to innovation and market-value is no recent realization. In 1983, the Small Business Innovation Research (SBIR) Act formalized government support of small businesses by directing federal agencies to contribute 3.2% of their R&D budget to small businesses through the SBIR program.

Naturally, the SBIR program is a primary vehicle of reform in AFWERX's strategy to redefine the defense industry landscape. Under AFWERX the SBIR program has taken steps to reduce barriers to startups constrained by short runways and limited familiarity with navigating government R&D contracts. Namely, a new class of contracts solicited under the umbrella term *Special Topics* has-among other things-reduced award timelines from months to weeks and introduced new application pathways so that companies can win contracts on-the-spot during *Pitch Days* or push their technology to Air Force end-users through *Open Topics*.

Anecdotally, the AFWERX community believes special topics are successful in attracting a new kind of R&D partner. At the inaugural open topics in New York, Dr. Roper, the Assistant Secretary of the Air Force for Acquisitions said, "the fact that these small businesses don't have to go get loans, or bridges, waiting for that 120 days to get on contract is a big deal... For the size of companies we saw this week, that paycheck today means they are now focused on our mission and not making payroll" [17]. Similarly bolstering the view that special topics stimulate new research partnerships is the emergence of matching funds from private equity and other government agencies. According to data supplied by AFWERX, the last cohort of awardees in 2019 brought in $15M from external government agencies and over $26M from private equity sources [37].

As AFWERX continues to iterate on special topics, it would benefit from understanding what modifications are tied to which outcomes. The confluence of other AFWERX programs alongside SBIR modifications, however, makes it difficult to disentangle the effects of myriad AFWERX programs from direct SBIR policy reforms. In hopes of informing AFWERX decision makers for future SBIR iterations, this paper seeks to isolate the effect of special topics, pitch days, and open topics on the composition of SBIR applicants. Specifically, this analysis focuses on Phase-I

applications because all SBIR awardees start with Phase-I [1].

A naïve approach would start and end with a direct comparison of companies applying to special topics with companies applying to conventional SBIR. These results are shown in Appendix A, and while they show what happened, they do not speak to counterfactual outcomes in a way that informs forward-looking decisions.

The interest of this paper is whether more desirable companies applied to Air Force's SBIR program *because* of the introduction of the Special Topic. Doing so would lend credibility to AFWERX's intuition that tedious application processes and sluggish awards have kept innovative small businesses from working with the Air Force in the past. In other words, this paper explores how policy reforms manifest in special topics differentially attract companies according to their characteristics.

Since the stated purpose of AFWERX is to attract highly-innovative small businesses, we focus on features most strongly associated with innovative start-ups to include financing status, company size, and previous engagement with SBIR.

Ultimately, this analysis addresses whether special topics bring innovative companies to the table that otherwise would not come. Following this up is an investigation into whether these new kinds of companies are more successful applying through special topics over the conventional SBIR program.

To answer these questions, we exploit the exogeneous shock of the Special Topic in a modified difference-in-differences approach. The analysis relies on applications to Air Force SBIR from 2016 through 2019. By comparing applicants before and after the introduction of special topics in 2018 (and comparing applicants between Special and conventional topics in the post period), the causal impact of a shift in application requirements on the composition of applicants. In addition to reducing application barriers, the analysis leverages two variants of special topics to isolate the impacts of removing technical requirements (open topics) and accelerating the evaluation process in pitch days. The analysis benefits from almost two years of conventional topics running concurrently with special topics. During this period, all topics were

[1] Direct to Phase II opportunities were introduced in the beginning of 2019 as previously discussed, however, it still holds Phase-I is the starting point for companies considering partnering with the government in R&D efforts

simultaneously broadcast through the same government website. In addition to examining whether special topics draw more desirable companies, this chapter investigates whether these previously disengaged companies are more successful in being awarded under the special topics evaluation process.

The results are striking. The cross-sectional results on special topics form a consistent narrative of expanding the pool of applicants in valuable directions. Namely, applicants have more venture capital backing, are smaller, and are not previous SBIR awardees. Furthermore, these shifts emerged more prominently over time, showing that adding special topics changed the trajectory of the applicant pool in an enduring way. Concerning selection results, the types of companies drawn by special topics are also more likely to be successful when applying through Special Topic.

The paper is organized as follows. Section 4.3 details the empirical setting, followed by section 4.4 with the empirical approach. Section 4.5 presents the data, defines variables and offers summary statistics. Section 4.6 presents empirical results for the first question, and section 4.7 reports results for the follow-on question. Section 4.8 concludes in discussion.

4.3 Empirical Setting

This section provide an overview of the natural experiments that shifted the Air Force's R&D application process in the following ways. Namely, special topics streamlined the application process, open topics put the onus on applicants to identify the research area, and pitch days gave applicants the chance for on-the-spot awards. A more detailed characterization of the changes to SBIR coordinated by AFWERX are laid out in Chapter three. To further facilitate an understanding of what changed and when, I also created an interactive timeline that traces changes and provides the option to filter applicants by solicitation period and topic type (application channel).

In early 2018 the SBIR government website released the list of SBIR topics, but this time alongside the conventional topics there were opportunities to apply to Air Force special topics with "accelerated timelines" [91]. In addition to bearing the

accelerated timelines of special topics, open topics had one more modification:"this topic is intended to be a call for open ideas and technologies that cover topics that may not be currently listed (i.e. the unknown-unknown)" [5]. Subsequent solicitations attracted an increasing number of applicants to special topics.

After the application deadline, applications to special topics were evaluated under an accelerated timeline through AFWERX but followed the same procedure as the conventional process; applications were independently scored on three criteria, and barring disqualifications were awarded if their sum was above a threshold.

4.4 Empirical Strategy

I examine the impact of the sudden introduction of new application channels on the composition of applicants. An effective estimation strategy must disentangle correlation from the direct impact. Ideally, isolating causal impact of the policy reforms manifest in special topics would rely on a controlled experiment in which companies are randomly assigned an opportunity to apply to either special topics or to their conventional counterpart. A practical route exploits the sudden introduction of new application channels, comparing companies across time and across the application channels.

A standard difference-in-differences approach implicitly controls for dynamic external influences such as the general availability of external finance, but this setting demands a modified version. While the difference-in-differences approach controls for omitted variable bias, in this case the vanilla difference-in-differences is susceptible to conflating an internal shift within the SBIR applicant pool for an application channel that draws companies that would otherwise not apply. This is because the shock *is* the instantiation of the treatment group (companies applying to special topics), so there is no way to observe the treatment group in the pre-period.

To work around this, the empirical approach is split into two parts. The first part considers the post-period and explores which company characteristics are explanatory of whether companies applied to special or conventional topics. The second part

observes the time-trend of the SBIR applicant pool in the pre and post periods, agnostic of whether companies applied through special topics. In addition to observing the entire program's time trend, part two checks for an immediate shift as well as a change in trend. This latter piece allows us to capture the appeal of special topics over time as its grows more distinct from conventional topics over time. Overall, this difference-in-differences strategy holds assumes that other than the direct policy reforms embodied in special topics, there are no time-varying factors which would have a differential effect on our treatment group relative to our control group.

4.4.1 Part One: Post Period Regression Specifications

For Parts One and Two, the baseline regression for investigating company composition takes the applicant's characteristic of interest as its dependent variable. Except for the number of employees, these characteristics are all binary-valued. For the cross sectional analysis of Part One, fixed effects on the five solicitation periods in the post period control for changing conditions over time. Specifically, the fixed effects account for the heterogeneity among the solicitation periods and the nonlinear evolution of company characteristics over time. Furthermore, indicator variables are included for whether an application was directed towards a special topic, with interactions for open topics and pitch days.

4.4.2 Part Two: Time Trend Regression Specifications

The time trend analysis consists of three separate regressions. The first regression only includes fixed effects on the solicitation period. Coefficients of solicitation period fixed effects provide insight into the evolution of the entire applicant pool with regards to the feature specified by the dependent variable.

The second regression puts a linear time trend on the solicitation period with an indicator for applications received in the post period. That each of the three annual solicitations are separated by four months means that the variable tracking solicitation period can follow any sequence of numbers with equal spacing. Integers

were a natural choice.

While the second regression captures a shift around the policy reform, a third regression investigates a change in trend across the policy reform. To accomplish this, the third regression adds an interaction term between the post period indicator and the time trend.

Together, these three regressions provide a visual overview of the time trend, which are then independently prodded for both nominal shifts and enduring changes in trend around the introduction of special topics. Whereas Part One picks up on the divergence between companies applying to special topics and those applying to conventional topics averaged across all time periods, Part Two provides a view of how the characteristics of these companies evolve over time. Part Two yields systematically underbiased distinctions between the pre and post periods because it is captures the net shift in applicants across both Special and conventional topics (necessary because of the absence of a pre period treatment group); and since Part One demonstrates a divergence between the two, this estimation over both groups tempers the results.

4.4.3 Follow On Investigation of Selection: Regression Specifications

After demonstrating that special topics attract a different population of companies, a natural opportunity arises to ask whether special topics also led to this new population successfully obtaining grant funding. To address this question, the dependent variable indicates whether a company's proposal was awarded. Again using fixed effects for the solicitation period, an interaction term between a Special Topic indicator and the company's characteristic of interest provides insight into how special topics differentially favor certain kinds of companies.

4.5 Data

The primary source of data in this study are comprised of applications merged to their evaluations for Air Force SBIR between 2016 and 2019, with the introduction of special topics at the second solicitation period of 2018. The applications and evaluations to conventional SBIR were compiled through coordination with the central SBIR office and after attaining the appropriate approval authorities [2]. AFWERX provided access to applications and evaluation sheets to the special topics. Together, this amounts to 10,336 observations of Phase-I applications to Air Force SBIR through special topics and conventional topics between 2016 and 2019. Figure 4-1 displays the number of Phase-I applications for each solicitation period, and reveals the growing proportion of applications to special topics. While the company size is a mandatory field in the application, the current financing status and previous award status were drawn from other sources.

Although applications and their evaluations were not available prior to 2016, all previous SBIR awardees are publicly available on the SBIR website. Through a rigorous matching process on both firm name and Dun & Bradstreet number (supervised by fuzzy matching), an application-level indicator was generated if the proposing company had ever been awarded in a previous solicitation period.

To extract the financing status of applying firms, a similarly rigorous matching on both firm name and company Uniform Resource Locator (URL) procedure was carried out with PitchBook deal-level data. Deal-level data was chosen because it provides company financial status at numerous time points, the most recently relevant of which was associated with the company's application. Mutually exclusive categories under financing status included Venture Capital (VC) backing, Accelerator/Incubator backing, Angel backing, Corporate Acquisition or backing, and Private Equity (PE) backing. In total there were fourteen categories (including None), but the other categories such as Formerly VC-Backed or Pending Transaction were too infrequent for statistical analysis. In this schema, 19% of applications were associated with a

[2] I would like to thank Sabrina Howell for compiling and sharing the conventional topics

financing status.

4.5.1 Missing Data

There is reason to believe the applications from 2016 do not represent the entire population because of a lapse in centralized management [3]. Although there is no reason to suspect systematic missing applications, Figure 4-1 shows that there are no Phase-I applications for the last solicitation period in 2016. There were, however, Phase II applications for this period. Also, since the coversheets for applications in 2016 were not complete, company size is only available for applications beginning in 2017. Aside from some missing applications in the pre-period, the completeness of post period applications was verified by cross-referencing proposal numbers, which uniquely identify an application, across the compiled applications and the compiled evaluations to a given solicitation period.

4.5.2 Variables and Summary Statistics

Table 4.1 provides variables and their definition, and Table 4.2 reports summary statistics. For Parts One and Two of the post-period cross-sectional analysis, the target variables of the regressions are company characteristics to include the number of *Employees*, and financing status: *Venture Capital*, *Private Equity*, *Angel*, *Accelerator or Incubator*, or *Corporate*. Marking the solicitation round that defines the time stamp of applications is *Solicitation* period. The second set of regressions that investigate the success of different kinds of companies relies on *Select* as the target variable. Table 4.2 depicts the award rates between Special and conventional topics for each solicitation period, with Special topics becoming increasingly competitive over time.

[3] After all, conventional Phase-I applications were evaluated by the unit that generated the topic [78], which was lower-level units such as Air Force Research Laboratory, so that there was less of a necessity to aggregate all applications.

Table 4.1: Application Level Data: Variables and Definitions

Variable	**Definition**	**Source**
Topic Characteristics		
Year	Marks year of application deadline	AFWERX
Solicitation Period	Marks the round (3/year)	AFWERX
Phase	Indicates phase-I or II (all Phase-I)	AFWERX
Topic Number	Specifies problem statement and solicitation	AFWERX
Conventional	Dummy for conventional SBIR topic	AFWERX
Special	Dummy for any AFWERX Special topic or variant	AFWERX
Special-Open	Dummy for Open variant of Special Topics	AFWERX
Special-Pitch	Dummy for Pitch Day variant of Special Topics	AFWERX
Company Characteristics		
Venture Capital	Dummy for VC backing	PitchBook
Angel	Dummy for angel backing	PitchBook
Accelerator/Incubator	Dummy for either program	PitchBook
Corporately Backed/Acquired	Dummy for corporately backed/acquired	PitchBook
Private Equity	Dummy for Private Equity backing	PitchBook
Never Previously Awarded	Dummy if applicant has previous Air Force SBIR award	AFWERX/SBIR.gov
Number of Employees	Company size is used to determine eligibility relative to NAICS	AFWERX
Other Information		
Select	Dummy for evaluation results	AFWERX/SBIR.gov

Table 4.2: Application Level Data: Phase-I Air Force SBIR

Year	2016	2017	2018	2019
Frequency	465	2015	3535	4321
Proportion	4.5%	19.5%	34.2%	41.8%

Topic Type	N	Proportion
Conventional	6,962	67.4%
Special	3374	32.6%
Special-Pitch	642	6.2%
Special-Open	2,021	19.6%

Financing Status of Applicant	N	Proportion
Venture Capital	775	7.5%
Private Equity	92	0.9%
Angel	161	1.6%
Accelerator or Incubator	360	3.5%
Corporate or Acquired	368	3.6%
None	858	83%

Company Size	Missing	Min	Max	Median	25th Perc.	75th Perc.
Employees	472	1	916	14	5	52

Award Rate by Sol.*	17.1	17.2	17.3	18.1	18.2	18.3	19.1	19.2	19.3
Conventional Topics	0.81	0.72	0.78	0.81	0.83	0.80	0.81	0.78	0.71
Special Topics	-	-	-	-	0.70	0.67	0.54	0.60	0.60

*Note: All applications from 2016 were selects

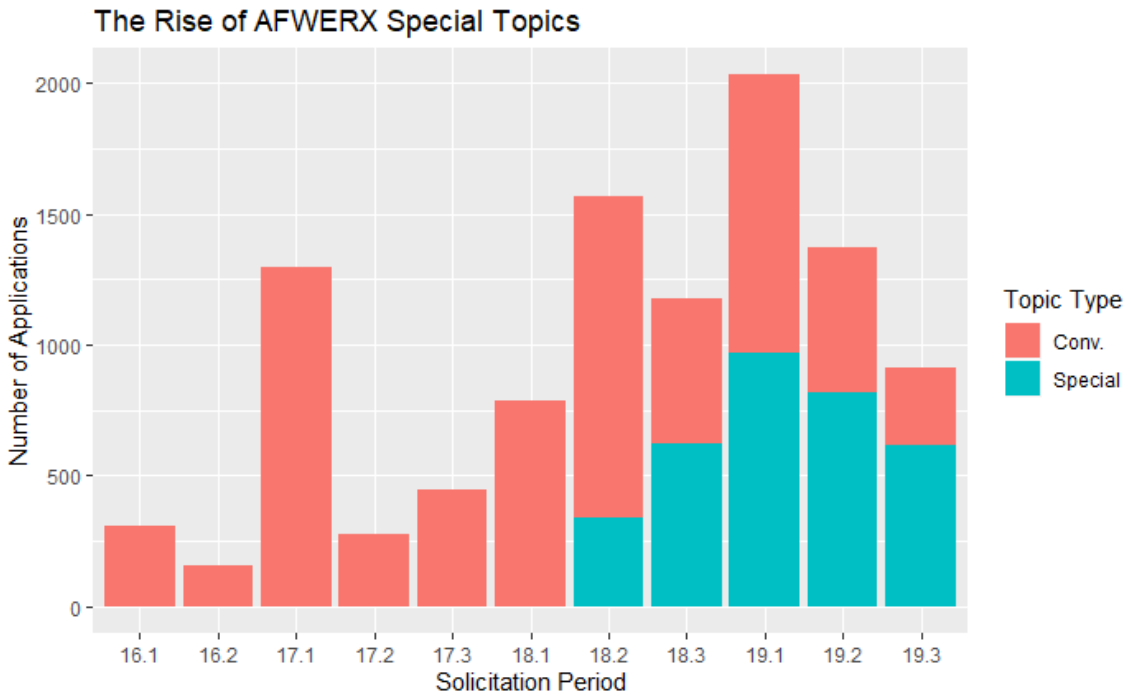

Figure 4-1: Phase 1 Applications in the Data Set. Note seasonality in first round of the year. The apparent dip in the end of 2019 is because of a shift towards more Phase-IIs which are 15-30 times more expensive than a Phase-I

4.6 Results: Special Topics Attract More Innovative Companies

We now turn to the estimates of the causal impact of special topics on the composition of the Air Force's SBIR applicant pool. As a preview of the evidence to follow, special topics draw companies that are smaller, more frequently backed by venture capital (and other private investment), and more frequently members of accelerators or incubators. In the opposite direction, special topics were less likely to attract companies with corporate backing or a previous SBIR award. Corporately backed firms, although more stable and generally more successful in SBIR applications, are presumably not as sensitive to administrative overhead required by the conventional process. Regarding previous award status, chapter three explains that the primary motivation behind special topics was mounting recognition that a static group of companies benefited from familiarity with the application process at the expense of

earlier-stage, innovative companies less inclined to endure a nine to twelve month award timeline.

To save the reader from a series of similar tables and figures, this section only walks through the results for one continuous target variable and one binary target variable. The rest of the results are presented in Appendix A. Also, all of our specifications report standard errors clustered by solicitation period.

4.6.1 Fewer Employees

special topics drew companies with fewer employees. This result emerged when using a natural log transformation of *Employees* as well as using a binned version for companies with less than ten employees. To orient the reader towards general trends, Figure 4-2 depicts the distribution of the logarithm of company size by solicitation period. A prescient review of Figure 4-2 invokes a premonition that is further buffered by the regression results. Namely, the shape of the distribution for Special applicants is distinct from that of conventional applicants.

Cross-section in the Post Period

First we consider the results of the cross-sectional analysis of the post-period with fixed effects on solicitation period. The regression results in Table 5.1 show that companies applying to special topics tend to have 57% fewer employees, on average, than those applying to conventional topics. The effect for companies applying to open topics is more pronounced, for a combined effect of 79% fewer employees. The effect of Pitch days on company size, however, is indistinguishable from the generic Special Topic.

Time Trends

Now that it is established that special topics differentially attract smaller companies in the post-period, Part Two of the experimental design is well situated to capture time trends. Using only fixed effects on solicitation period to predict company size,

Figure 4-2: Applications in 2016 are missing data, but after solicitation period 18.2 (May 2018), the company size of Special topic applicants concentrates towards fewer employees.

Table 4.3

	Dependent variable:
	log(Number of Employees)
	OLS
Special	−0.57 (0.06)
	p = 0.00***
Special-Open	−0.22 (0.06)
	p = 0.001***
Special-Pitch	0.01 (0.08)
	p = 0.87
Constant	3.20 (0.04)
	p = 0.00***
Solicitation F.E.'s?	Yes
Observations	7,067
R^2	0.07
Adjusted R^2	0.07
Residual Std. Error	1.36 (df = 7059)
Note:	*p<0.1; **p<0.05; ***p<0.01
	(Standard Errors): Clustered to Solicitation, type = HC0

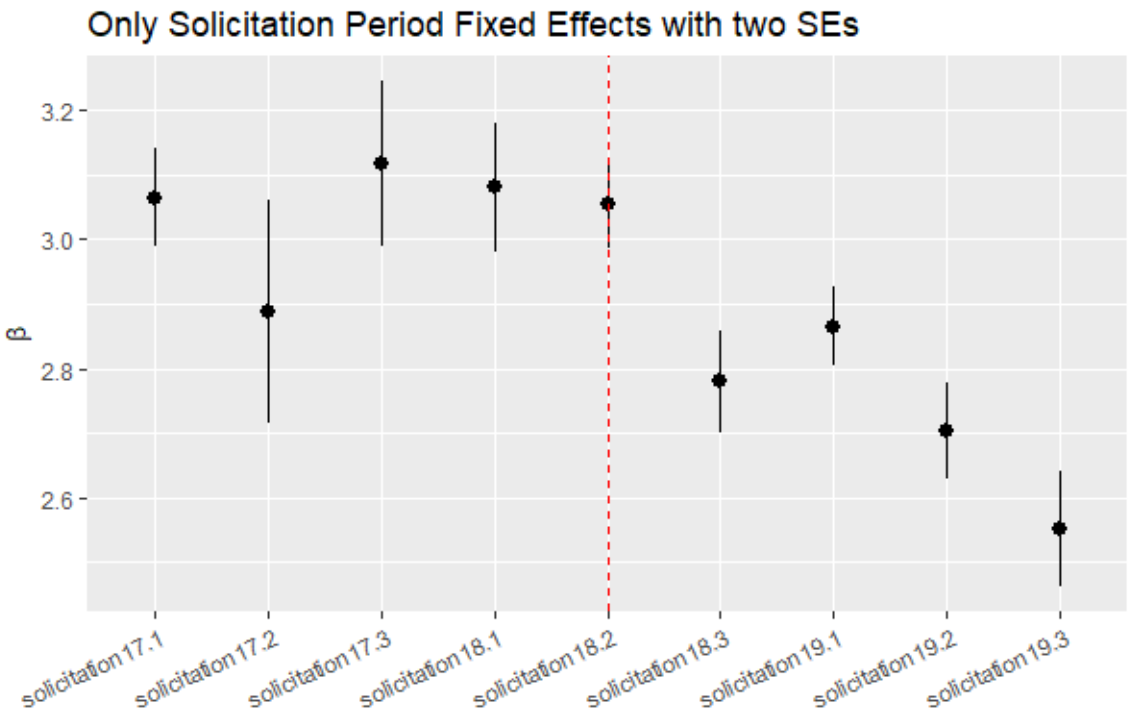

Figure 4-3: The plotted coefficients are from the model that regresses *Log(Employees + 1)* on *Solicitation Period*

Figure 4-3 visualizes the time trend around the introduction of special topics. In order to detect whether the shift in company size is best explained as an immediate shift or as an emerging trend (or both), we turn to the second and third parts of the time trend analysis. Fitting a linear trend on solicitation period with an indicator for the post period yields a tension between the time trend and the indicator intended to pick up an immediate shift after the introduction of special topics. Remembering that the time trend analysis is agnostic of whether the company applied to a Special Topic, the coefficient on solicitation period suggests a significant downward trend in company size of SBIR applicants. This, however, reduces the space for the post period indicator to also pick up on an immediate shift since the linear time trend is also pulling the model this same direction. Table 4.4 displays this dynamic. Table 4.5 resolves this tension by showing that the change in company size is best described as a change in trend across the policy reform, rather than an immediate shift. This view is buttressed by Figure 4-2, which shows initially similar distributions across Special

Table 4.4

	Dependent variable:
	log(Number of Employees)
	OLS
Solicitation (Numeric)	−0.08 (0.01)
	p = 0.00***
Post Period (Dummy)	0.11 (0.06)
	p = 0.07*
Constant	3.46 (0.06)
	p = 0.00***
Observations	9,864
R^2	0.01
Adjusted R^2	0.01
Residual Std. Error	1.41 (df = 9861)
Note:	*p<0.1; **p<0.05; ***p<0.01
	(Standard Errors): Clustered to Solicitation, type = HC0

and conventional topics morphing into very different distributions by 2019.

Table 4.5

	Dependent variable:
	log(Number of Employees)
	OLS
Solicitation (Numeric)	0.01 (0.02)
	p = 0.60
Post Period (Dummy)	0.89 (0.17)
	p = 0.0000***
Solicitation:Post Period	−0.12 (0.02)
	p = 0.0000***
Constant	3.00 (0.11)
	p = 0.00***
Observations	9,864
R^2	0.01
Adjusted R^2	0.01
Residual Std. Error	1.40 (df = 9860)
Note:	*p<0.1; **p<0.05; ***p<0.01
	(Standard Errors): Clustered to Solicitation, type = HC0

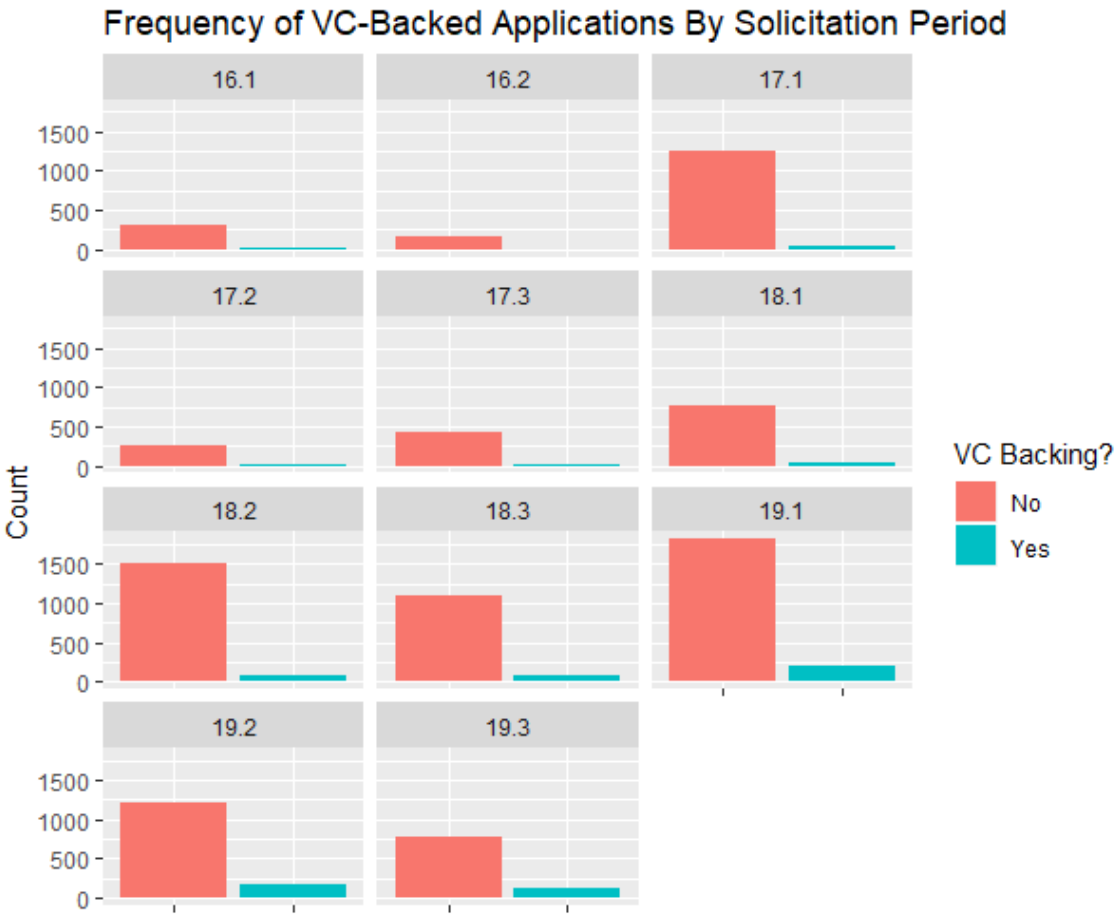

Figure 4-4: VC backed applications become more frequent after the introduction of special topics. At their peak in the last solicitation of 2019, VC-backed applications represent 13.8% of all Phase-I applications to SBIR.

4.6.2 More Venture Capital Backing

This section presents remarkable results on venture capital backing as a binary dependent variable of the following sequence of regressions. To orient the reader, Figure 4-4 depicts the frequency of venture capital backed applications by solicitation period.

Cross-Section in the Post Period

According to the results in Table 4.6, applicants to special topics are in expectation 77% more likely to be venture backed. For Open topics, this increases to 146%, and

with pitch days the numbers show an increase of 132% from conventional topics. This increase should be taken into context with the absolute frequency, which even for special topics averages over time to 15%.

Table 4.6

	Dependent variable:
	Venture Capital Backing
	logistic
Special	0.77 (0.16)
	p = 0.0000***
Special-Open	0.69 (0.16)
	p = 0.0001***
Special-Pitch	0.56 (0.19)
	p = 0.004***
Constant	−3.41 (0.14)
	p = 0.00***
Solicitation F.E.'s?	Yes
McFadden Pseudo R^2	0.07
Observations	7,068
Log Likelihood	−2,047.14
Note:	*p<0.1; **p<0.05; ***p<0.01
	(Standard Errors): Clustered to Solicitation, type = HC0

Time Trends

Similar to the cross-sectional results, the time trend for venture capital backing is astonishing, turning up right at the introduction of special topics as shown in Figure 4-5. Whereas the time trend for the number of employees was less explicit in the preliminary visualization of solicitation fixed effect, Tables 4.7 and 4.8 exhibit a dramatic change that strengthens from the policy reforms through 2019.

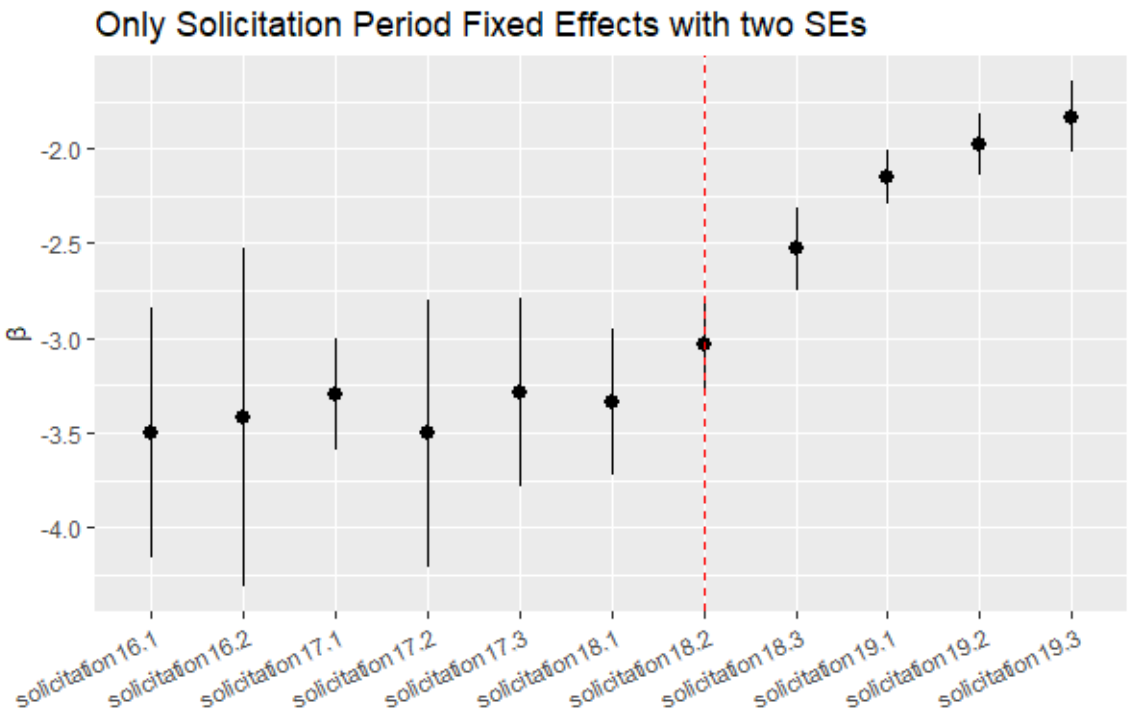

Figure 4-5: The plotted coefficients are from the model that regresses *Venture Capital Backing (1/0)* on *Solicitation Period*

Table 4.7

	Dependent variable:
	Venture Capital Backing (Dummy)
	logistic
Solicitation (Numeric)	0.22 (0.05)
	p = 0.0001***
Post Period (Dummy)	−0.01 (0.36)
	p = 0.99
Constant	−4.45 (0.33)
	p = 0.00***
McFadden Pseudo R^2	0.04
Observations	10,336
Log Likelihood	−2,654.40
Note:	*p<0.1; **p<0.05; ***p<0.01
	(Standard Errors): Clustered to Solicitation, type = HC0

Table 4.8

	Dependent variable:
	Venture Capital Backing (Dummy)
	logistic
Solicitation (Numeric)	0.02 (0.01)
	p = 0.15
Post Period (Dummy)	−1.69 (0.46)
	p = 0.0003***
Solicitation:Post Period	0.27 (0.04)
	p = 0.00***
Constant	−3.43 (0.07)
	p = 0.00***
McFadden Pseudo R^2	0.04
Observations	10,336
Log Likelihood	−2,645.50
Note:	*p<0.1; **p<0.05; ***p<0.01
	(Standard Errors): Clustered to Solicitation, type = HC0

4.7 Results: Was this new applicant pool successful?

Under AFWERX, SBIR special topics attracted a distinctly divergent group of applicants. It turns out, as shown in Figure 4.9, that companies responded rationally in that they applied to topics where they had the best chances of success. Most prominently, companies that have fewer employees and are backed by venture capital are more successful in Special topics than in conventional topics. Furthermore, these results reveal that previously awarded companies are on average 161% less likely to be successful reapplying through special topics than through conventional topics.

4.8 Discussion

In previous chapters of this thesis, I motivate the paradigm shift towards open innovation in the Air Force. For the SBIR program that means engaging a broader pool of companies; more specifically, companies that are more promising in their potential to develop novel and useful technologies that further national security while

Table 4.9

	Dependent variable:					
	Awarded (Dummy)					
	logistic					
	(1)	(2)	(3)	(4)	(5)	(6)
Special	−1.18 (0.21)	−0.96 (0.14)	−0.91 (0.15)	−0.85 (0.15)	0.66 (0.10)	0.59 (0.56)
	p = 0.0000***	p = 0.00***	p = 0.00***	p = 0.0000***	p = 0.00***	p = 0.30
LessThan10	−1.93 (0.12)					−0.31 (0.21)
	p = 0.00***					p = 0.14
Special:LessThan10	0.84 (0.18)					−0.18 (0.32)
	p = 0.0000***					p = 0.57
VC		−0.13 (0.20)				−0.45 (0.43)
		p = 0.53				p = 0.30
Special:VC		0.61 (0.29)				1.22 (0.51)
		p = 0.04**				p = 0.02**
Accel./Incub.			−0.85 (0.22)			−0.38 (0.11)
			p = 0.0001***			p = 0.001***
Special:Accel./Incub.			0.81 (0.22)			0.78 (0.08)
			p = 0.0002***			p = 0.00***
Corp./Acqr'd				2.10 (0.63)		1.36 (1.05)
				p = 0.001***		p = 0.20
Special:Corp./Acqr'd				−0.73 (0.51)		−0.22 (0.95)
				p = 0.16		p = 0.82
Prev. Awarded					5.53 (0.17)	5.37 (0.20)
					p = 0.00***	p = 0.00***
Special:Prev. Awarded					−1.61 (0.23)	−1.49 (0.76)
					p = 0.00***	p = 0.06*
Solicitation Fixed Effects?	Yes	Yes	Yes	Yes	Yes	Yes
Constant Not Shown?	Yes	Yes	Yes	Yes	Yes	Yes
Observations	7,067	7,068	7,068	7,068	7,068	7,067
Log Likelihood	−3,722.51	−4,071.07	−4,077.11	−4,050.88	−2,155.17	−2,103.20
McFadden R^2	0.13	0.05	0.05	0.05	0.5	0.51

Note: *p<0.1; **p<0.05; ***p<0.01
(Standard Errors): Clustered to Solicitation, type = HC0

adding economic value. Through a modified difference-in-differences approach this chapter presents evidence that special topics draw companies stronger in measures of innovation to include venture backing, company size, and absence of a previous SBIR award.

In summary, three results are particularly striking. First, cross-sectional results form a consistent narrative of expanding the pool of applicants in valuable directions. Second, the time trend analysis demonstrates a change in trend: adding special topics changed the trajectory of the applicant pool in a substantial and long-lasting way. Lastly, companies responded rationally in that they applied to the application channel most favorable to them. Or in other words, the new pool of applicants were also more successful under special topics. This is unexpected because the evaluation framework under special topics and conventional topics is nominally the same; three criteria are scored, each by different evaluators, and barring disqualifications any application above a threshold is awarded. While there is more room for soft information to inform Phase-II awards [29], the Phase-I evaluation process is rather straightforward. The results presented in this work, however, may point to the influence of soft information in evaluation outcomes as manifest in opposing preferences between special and conventional evaluators for similar companies.

Beyond these direct implications, this line of work touches on questions of policy. First, the statutory intent of the SBIR program is to stimulate research and development efforts, implying it should focus on areas not already supported by private sector funding. In fact, the trend towards dual-use technologies reveals an intrinsic tension between the two-fold goals of SBIR. If SBIR is to help the DoD perform its public duty, this end is more immediately attained through adapting already available technologies, but this comes at the expense of under-funded sectors or exploratory research.

Further consideration of the nature of technology development through an open innovation lens, however, resolves some of this tension. According to the theory of open innovation, novel technologies are the product of a paradigm that does not cling too tightly to proprietary knowledge [80]. As boundaries become more permeable and

roles more flexible, it becomes less evident that forcing government research dollars to the unwanted fringes is necessary. Big tech firms are trying their hand at moonshots traditionally associated with DARPA in addition to collaborating with universities performing more exploratory research. This discussion does not, however, completely appease concern that a shift towards dual-use leaves early stage theoretical work to the wayside.

A second area of policy interest is the potential to incorporate algorithmic evaluations of SBIR applications. An obvious starting point are Phase-I applications where less money is at stake and there is more room for the Law of Large Numbers to absorb risk. Following this track, three problems immediately arise. If the model is interpretable then it is susceptible to adversarial behavior by applicants. Furthermore, a completely automated process leaves AFWERX less room to leverage soft information as it apparently already may be doing, even if inadvertently. Third is that what constitutes a successful application is changing and training models on historical data is antithetical to the positive direction we are moving.

The last area of policy interest is one that concerns longer-term outcomes. The current evaluation process for Phase-II applications relies on a signed statement of interest from Air Force stakeholders to verify that the proposed technology meets an need. While this provides ground-level users authority to identify Air Force needs, it is not clear what incentive an Air Force stakeholder would have to refuse help if the money does not detract from their operating allotment. This may be particularly precarious with innovative startups brandishing artificial intelligence or machine learning as a panacea.

In conclusion, this chapter presents evidence that special topics attract a more desirable pool of applicants, and follows this up with evidence that special topics favor this new more innovative group of companies relative to the conventional evaluation.

Chapter 5

Appendix A

Appendix A presents the rest of the regression results for chapter four's econometric analysis of AFWERX special topics.

5.1 (-) Company Size

The binned target variable provides more statistical power, but tells a similar story reported by the continuous variable included in the body of Chapter 4.

Table 5.1

	Dependent variable:
	Less Than Ten Employees (Dummy)
	logistic
Special	0.65 (0.10)
	p = 0.00***
Special-Open	0.24 (0.13)
	p = 0.08*
Special-Pitch	0.03 (0.17)
	p = 0.86
Constant	−0.80 (0.01)
	p = 0.00***
Solicitation F.E.'s?	Yes
McFadden Pseudo R^2	0.03
Observations	7,067
Log Likelihood	−4,671.12
Note:	*p<0.1; **p<0.05; ***p<0.01
	(Standard Errors): Clustered to Solicitation, type = HC0

Table 5.2

	Dependent variable:
	Less Than Ten Employees (Dummy)
	logistic
Solicitation (Numeric)	0.11 (0.04)
	p = 0.01***
Post Period (Dummy)	−0.15 (0.24)
	p = 0.54
Constant	−1.18 (0.23)
	p = 0.0000***
McFadden Pseudo R^2	0.01
Observations	9,864
Log Likelihood	−6,630.77
Note:	*p<0.1; **p<0.05; ***p<0.01
	(Standard Errors): Clustered to Solicitation, type = HC0

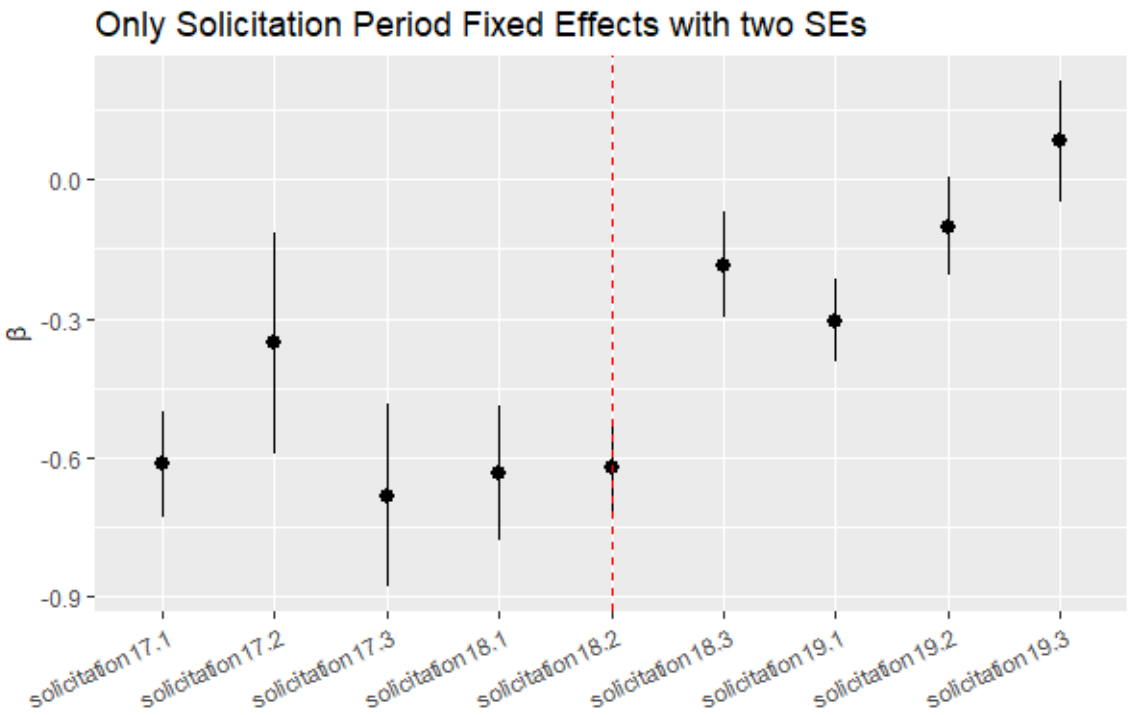

Figure 5-1: The plotted coefficients are from the model that regresses *Less than 10 Employees (1/0)* on *Solicitation Period*

Table 5.3

	Dependent variable:
	Less Than Ten Employees (Dummy)
	logistic
Solicitation (Numeric)	−0.01 (0.01)
	p = 0.25
Post Period (Dummy)	−1.24 (0.32)
	p = 0.0001***
Solicitation:Post Period	0.17 (0.03)
	p = 0.0000***
Constant	−0.53 (0.09)
	p = 0.00***
McFadden Pseudo R^2	0.01
Observations	9,864
Log Likelihood	−6,619.76
Note:	*p<0.1; **p<0.05; ***p<0.01
	(Standard Errors): Clustered to Solicitation, type = HC0

5.2 (+) Investment Backing (VC, Angel, PE)

If companies with Angel or Private Equity backing were more frequent, I would have investigated them separately. As an alternative I combined the three to offer a more general insight into any investment backing trends. Although not apparent in the results, it seems likely that private equity and angel backing pull in opposite directions. Private Equity firms generally invest in older companies an expect to make a profit by streamlining operations and reselling the company. Angel investors, however, often precede venture capital funds in the nascent stages of a company's life

Figure 5-2 shows the relative frequency, Table 5.4 shows the cross sectional results, and Tables 5.5 and 5.6 provide the time trend analysis alongside the visualization of the fixed effects coefficients on solicitation period in Figure 5-3.

Table 5.4

	Dependent variable:
	VC, Angel, or Private Equity
	logistic
Special	0.78 (0.20)
	p = 0.0001***
Special-Open	0.58 (0.09)
	p = 0.00***
Special-Pitch	0.49 (0.16)
	p = 0.003***
Constant	−3.06 (0.06)
	p = 0.00***
Solicitation F.E.'s?	Yes
McFadden Pseudo R^2	0.07
Observations	7,068
Log Likelihood	−2,449.77
Note:	*p<0.1; **p<0.05; ***p<0.01
	(Standard Errors): Clustered to Solicitation, type = HC0

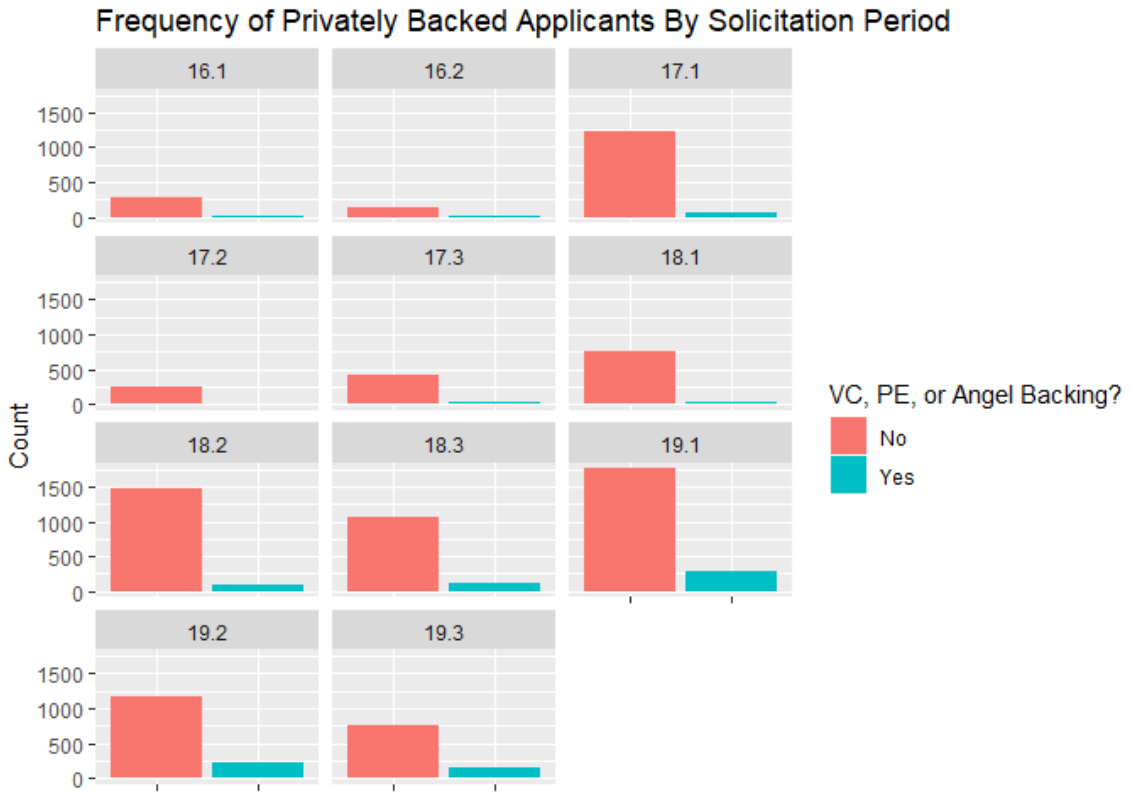

Figure 5-2: Air Force Phase-I SBIR Applications: Venture Capital, Private Equity, and Angel backed applications are more frequent after the introduction of special topics, climbing from 3.5% in the beginning of 2016 to 17.4% by the end of 2019. Evidence for causality is provided through the regressions.

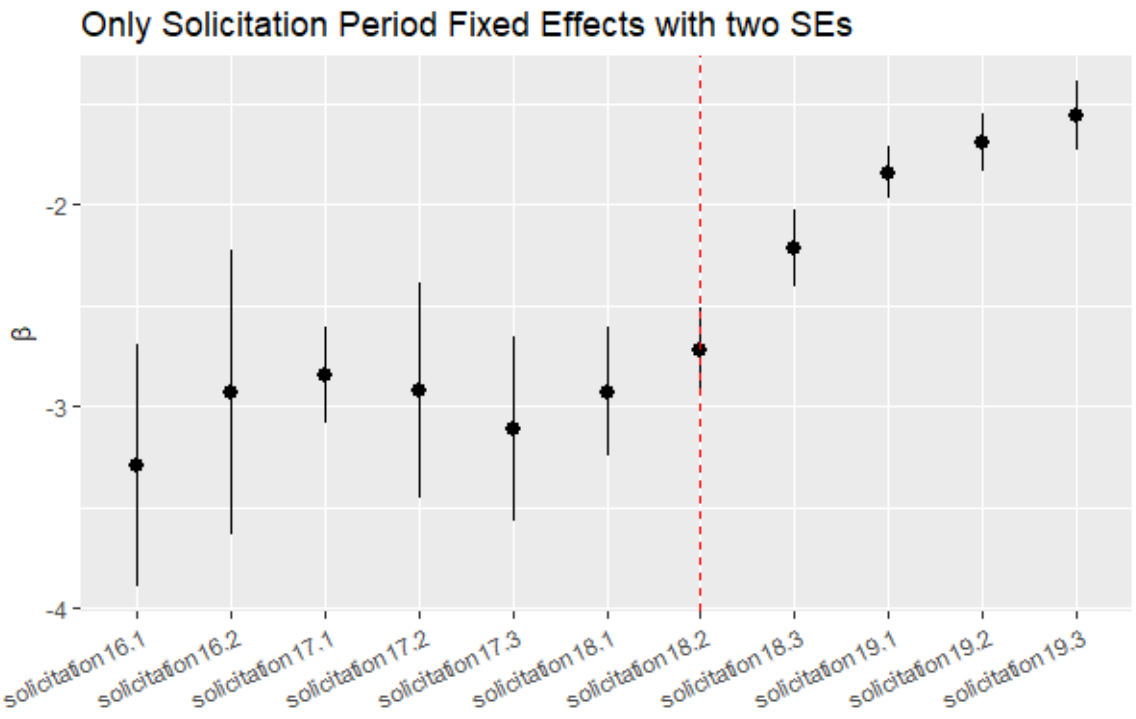

Figure 5-3: The plotted coefficients are from the model that regresses *VC, Angel or PE Backing (1/0)* on *Solicitation Period*

Table 5.5

	Dependent variable:
	Venture Capital, Angel, or Private Equity Backed (Dummy)
	logistic
Solicitation (Numeric)	0.21 (0.05)
	p = 0.0002***
Post Period (Dummy)	−0.05 (0.37)
	p = 0.90
Constant	−3.97 (0.34)
	p = 0.00***
McFadden Pseudo R^2	0.03
Observations	10,336
Log Likelihood	−3,237.10
Note:	*p<0.1; **p<0.05; ***p<0.01
	(Standard Errors): Clustered to Solicitation, type = HC0

Table 5.6

	Dependent variable:
	Venture Capital, Angel, or Private Equity Backed (Dummy)
	logistic
Solicitation (Numeric)	0.02 (0.03)
	p = 0.58
Post Period (Dummy)	−1.70 (0.51)
	p = 0.001***
Solicitation:Post Period	0.26 (0.05)
	p = 0.0000***
Constant	−3.03 (0.18)
	p = 0.00***
McFadden Pseudo R^2	0.04
Observations	10,336
Log Likelihood	−3,225.39
Note:	*p<0.1; **p<0.05; ***p<0.01
	(Standard Errors): Clustered to Solicitation, type = HC0

5.3 (+) Accelerator or Incubator Companies

Even in the post period, companies identified by PitchBook as current members of an accelerator or incubator program were infrequent. In the pre-period they were nonexistent so the time trend analysis is not a viable option.

Figure 5-4 shows the relative frequency, and Table 5.7 shows the cross sectional results.

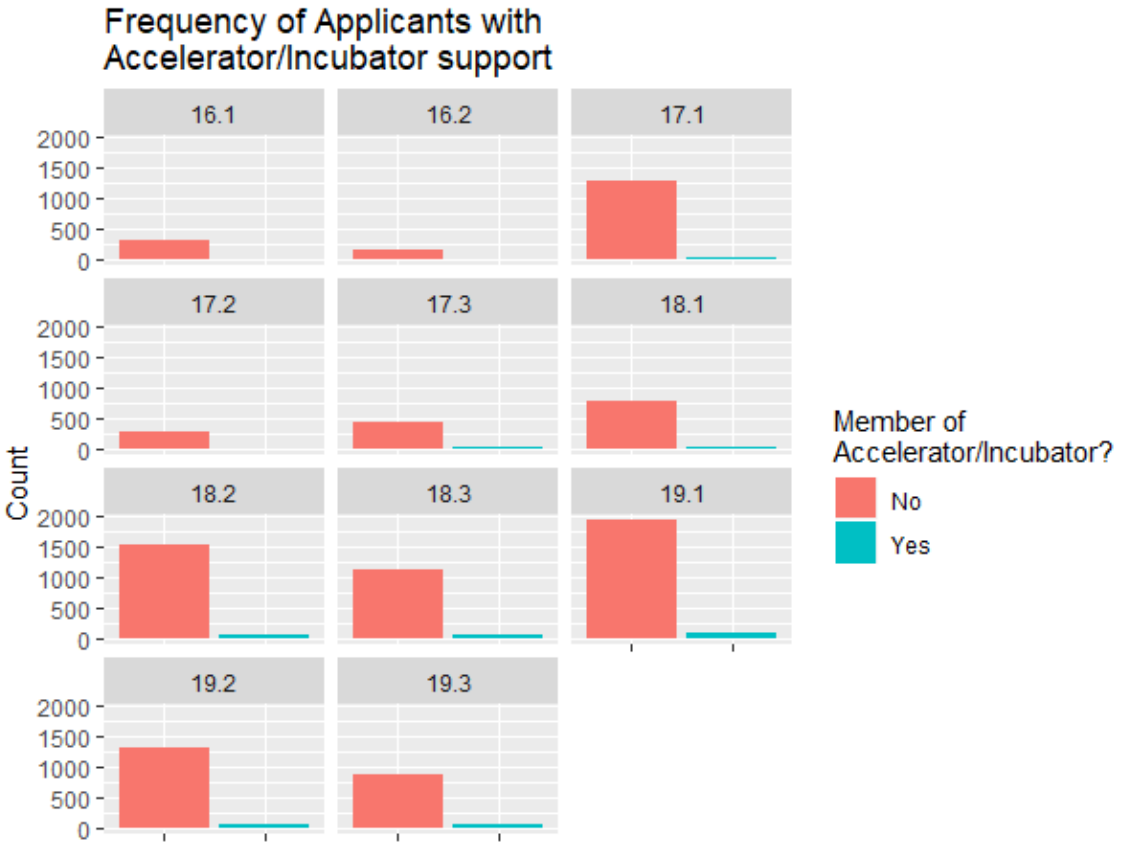

Figure 5-4: Air Force Phase-I SBIR Applications. Emerging businesses in incubator or technology accelerator programs are more frequent after the introduction of special topics, climbing from less than 1% in the beginning of 2016 to 5% by the end of 2018.

Table 5.7

	Dependent variable:
	Accelerator or Incubator Backed
	logistic
Special	1.31 (0.24)
	p = 0.0000***
Special-Open	0.12 (0.13)
	p = 0.36
Special-Pitch	−0.49 (0.09)
	p = 0.0000***
Constant	−3.85 (0.14)
	p = 0.00***
Solicitation F.E.'s?	Yes
McFadden Pseudo R^2	0.05
Observations	7,068
Log Likelihood	−1,208.49

Note: *p<0.1; **p<0.05; ***p<0.01
(Standard Errors): Clustered to Solicitation, type = HC0

5.4 (-) Corporately Backed or Acquired companies

Corporately backed or acquired firms were considered separately, because the observations were frequent enough and because it displayed trends not seen with any other form of financial status. The results for corporately backed or acquired firms had less clear-cut time trends but were clearly divergent from Special topics in the cross sectional analysis.

Figure 5-5 shows the relative frequency, Table 5.8 shows the cross sectional results, and Tables 5.9 and 5.10 provide the time trend analysis alongside the visualization of the fixed effects coefficients on solicitation period in Figure 5-6.

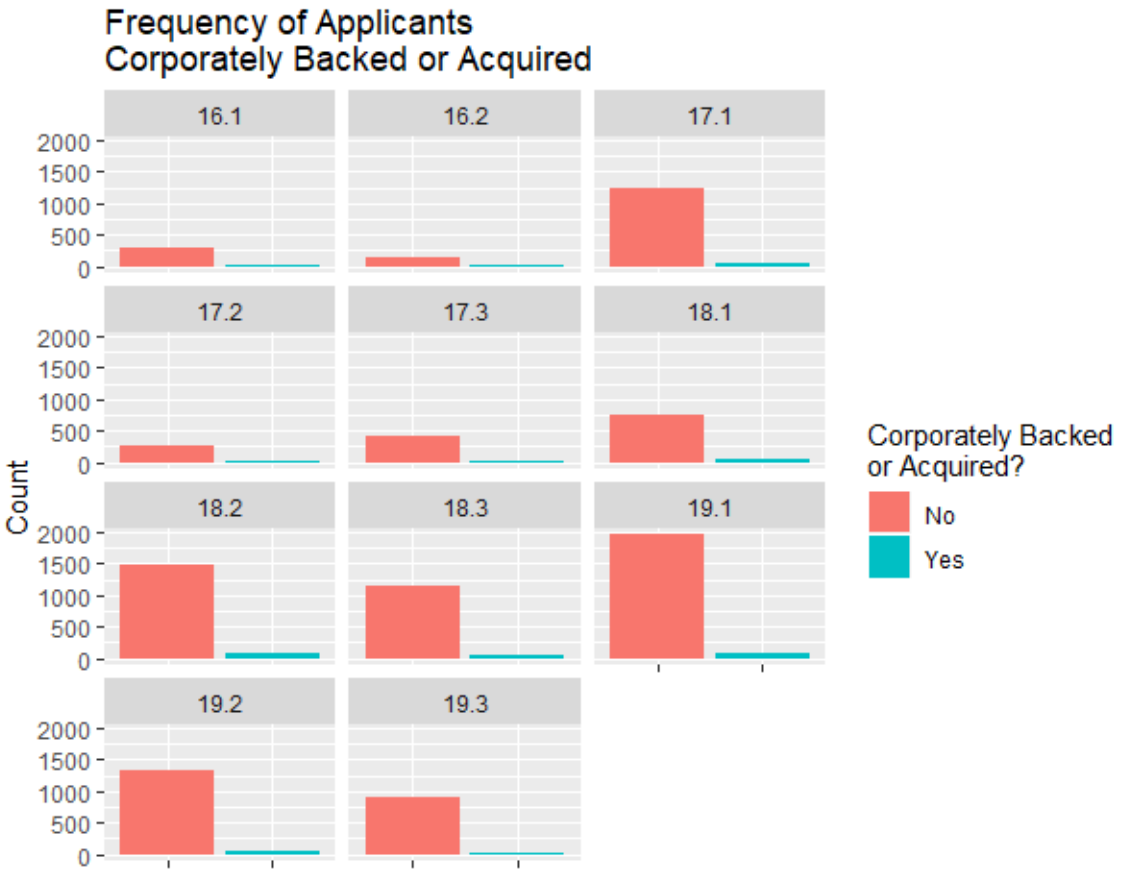

Figure 5-5: Air Force Phase-I SBIR Applications–judging proportions is difficult, but corporately backed or acquired applicants peak at 5% in the middle of 2018 and decrease to 1.6% by the end of 2019.

Table 5.8

	Dependent variable:
	Corporately Backed or Acquired
	logistic
Special	−0.94 (0.24)
	p = 0.0002***
Special-Open	−0.67 (0.43)
	p = 0.12
Special-Pitch	−0.51 (0.25)
	p = 0.05**
Constant	−2.76 (0.01)
	p = 0.00***
Solicitation F.E.'s?	Yes
McFadden Pseudo R^2	0.05
Observations	7,068
Log Likelihood	−989.32
Note:	*p<0.1; **p<0.05; ***p<0.01
	(Standard Errors): Clustered to Solicitation, type = HC0

Table 5.9

	Dependent variable:
	Corporately Backed or Acquired (Dummy)
	logistic
Solicitation (Numeric)	−0.07 (0.07)
	p = 0.34
Post Period (Dummy)	0.18 (0.42)
	p = 0.68
Constant	−2.87 (0.33)
	p = 0.00***
McFadden Pseudo R^2	0
Observations	10,336
Log Likelihood	−1,585.69
Note:	*p<0.1; **p<0.05; ***p<0.01
	(Standard Errors): Clustered to Solicitation, type = HC0

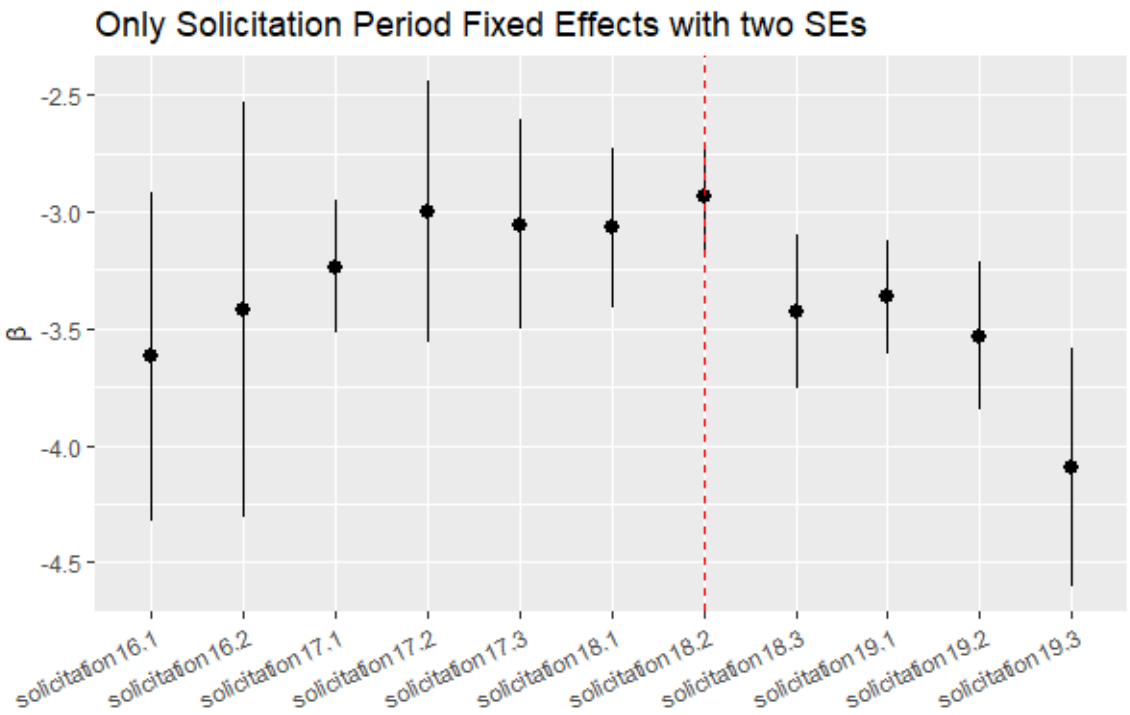

Figure 5-6: The plotted coefficients are from the model that regresses *Corporately Backed or Acquired (1/0)* on *Solicitation Period*

Table 5.10

	Dependent variable:
	Corporately Backed or Acquired (Dummy)
	logistic
Solicitation (Numeric)	0.08 (0.02)
	p = 0.0000***
Post Period (Dummy)	2.40 (0.35)
	p = 0.00***
Solicitation:Post Period	−0.31 (0.04)
	p = 0.00***
Constant	−3.58 (0.08)
	p = 0.00***
McFadden Pseudo R^2	0.01
Observations	10,336
Log Likelihood	−1,576.35
Note:	*p<0.1; **p<0.05; ***p<0.01
	(Standard Errors): Clustered to Solicitation, type = HC0

5.5 (+) New Companies

Table 5.11

	Dependent variable:
	Previously Awarded AF SBIR
	logistic
Special	−1.02 (0.13)
	p = 0.00***
Special-Open	−0.53 (0.28)
	p = 0.07*
Special-Pitch	−0.33 (0.34)
	p = 0.34
Constant	1.45 (0.05)
	p = 0.00***
Solicitation F.E.'s?	Yes
McFadden Pseudo R^2	0.12
Observations	7,068
Log Likelihood	−4,181.70
Note:	*p<0.1; **p<0.05; ***p<0.01
	(Standard Errors): Clustered to Solicitation, type = HC0

While the cross-sectional analysis in the post period is valid and striking, the time trend analysis is not fit for a measure that is inherently autocorrelated with time. As more companies are awarded, there is a greater pool of previous awardees and hence we should expect an increase in returning awardees over time. The follow-up analysis on selection between special and conventional topics tells us that previously awarded companies are decidedly less successful when applying to special topics.

Figure 5-7 shows the relative frequency, Table 5.11 shows the cross sectional results, and Figure 5-8 plots the solicitation fixed effects.

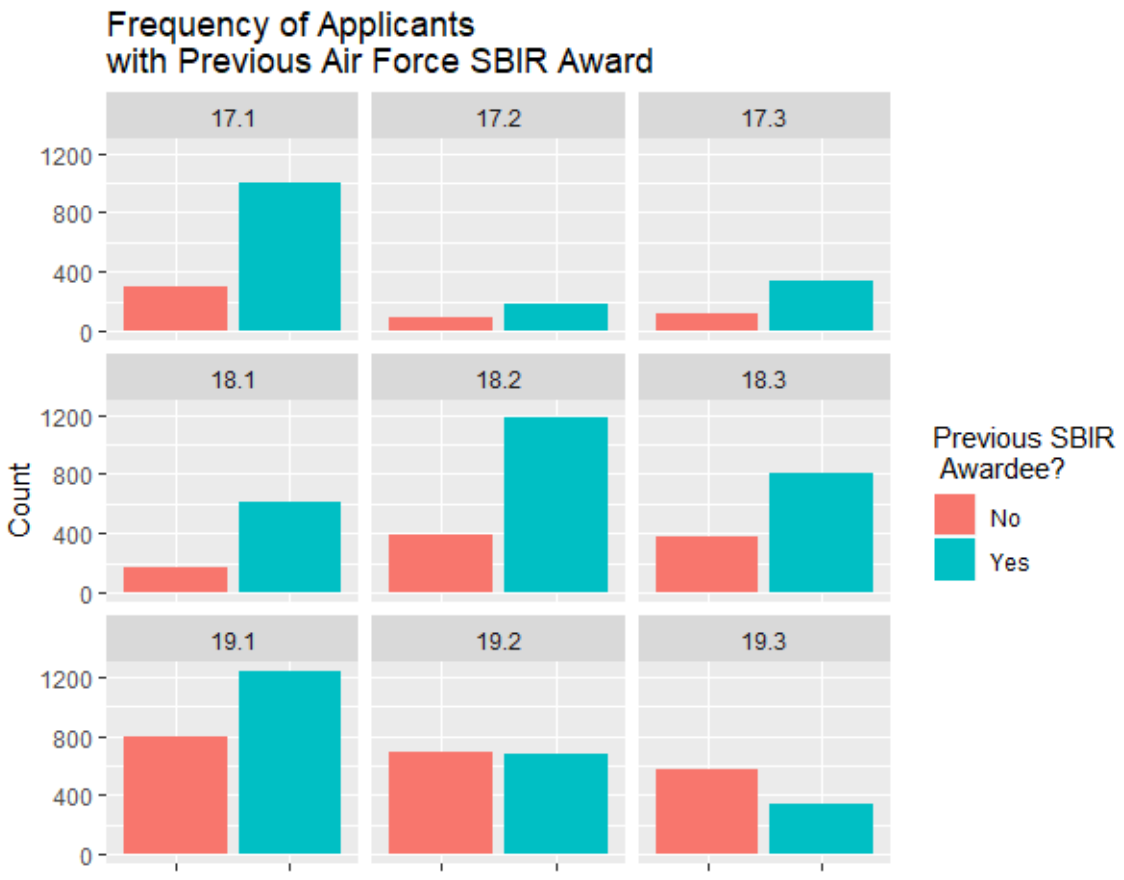

Figure 5-7: Air Force Phase-I SBIR Applicants: In the pre-period, more than 70% of applicants are previous Air Force SBIR awardees, but this sinks to 37% by the end of 2019. The data for 2016 is left out because the previous award indicator was generated through matching on DUNS, but for 2016 applications DUNS was missing.

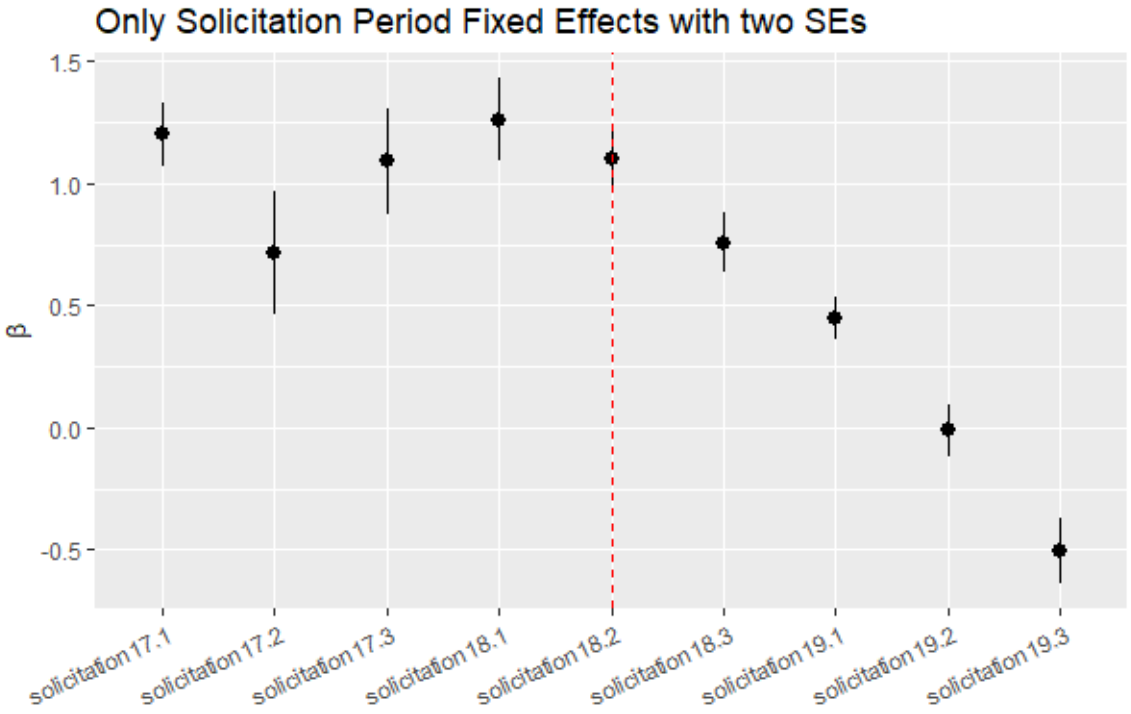

Figure 5-8: The plotted coefficients are from the model that regresses *Previously Awarded Air Force SBIR (1/0)* on *Solicitation Period*

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