A COMPARISON OF SBIR INVESTMENT METHODS: AFWERX VS LEGACY

THESIS

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Abstract

The AFWERX Open Topic (AOT) program uses funding from the United States Air Force's (USAF) Small Business Innovation and Research (SBIR) budget to adapt commercial technology to USAF needs. The AOT approach to small business investment is markedly different from that of legacy SBIR investment methods. This research is a comparison of processes and outcomes for AOT and legacy SBIR.

The first axis of comparison is on *commercialization rates*. Applying a legacy definition of commercialization on a sample of AOT contracts, we found AOT's commercialization to be 37% (compared to an 8.8% for legacy SBIR). We caveat this finding by pointing out the ways a commercialization comparison of the two SBIR methods might be appropriate.

The next comparison considered the military capabilities each process invested in. AOT contracts were binned into Joint Capability Areas (JCA) to create an AOT military capability portfolio (MCP) which was then compared to a legacy SBIR MCP. Results suggest legacy SBIR invests at higher rates in the Force Application JCA while AOT investment rates are higher in the Force Integration and Command & Control JCAs.

The final comparison considers the success of AFWERX's strategy of creating technical centers (or 'front doors') in regions known for being bastions of innovation (i.e., AFWERX Austin) by a simple test of differences between AOT and legacy regional SBIR participation rates. In Texas and Washington District of Columbia (DC), regions with AFWERX centers, AOT participation rates were statistically higher than legacy SBIR.

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Evan A. Gist

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I. Chapter One - Introduction

1.1 Background

Senior Department of Defense (DoD) officials have been raising the alarm about a fundamental weakness of the DoD's acquisition process – it was not optimized for the current pace and location of technological change (Secretary of Defense, 2018; Assistant Secretary of the Air Force for Acquisition, Technology and Logistics, 2019; Secretary of the Air Force, 2017). Innovations occur more frequently now than at other times in history. This is particularly true in the areas of communications and computing, where innovations are occurring in short cycles of less than 36-months (or weeks in the case of software) (Spataro, 2018). Unfortunately, the DoD has not been able to capitalize on this change in the external technical environment.

Despite the uptick in the speed of innovation cycles, the DoD acquisition process lacks the mechanisms to benefit from them. The current mechanisms of acquisition, including the Joint Capabilities Integration and Development System (JCIDS) process and the Defense Acquisition System (DAS), seem designed for full-rate production programs that take decades of development (Spataro, 2018). In response to this inability to adapt to a shifting innovation landscape, defense officials have been experimenting with alternatives to the legacy systems which (hopefully) provide timely and continuous delivery of capability to the warfighter in a way the current system cannot. One of those experiments for the Unites States Air Force (USAF) is an organization called AFWERX, and AFWERX has a program called the AFWERX Open Topic program (AOT) which seeks to disrupt and improve upon legacy methods of Small Business Innovation and Research (SBIR) investment.

Comparison of the AOT and the legacy SBIR program is the primary focus of this research. We begin that comparison with a jump back in time. Early on the morning of January 11th, 2018, Vice President of the United States Mike Pence and Air Force Secretary Heather Wilson traveled to a business park in Las Vegas, Nevada, to give the opening remarks for a ceremony celebrating the creation of AFWERX Vegas. Secretary Wilson gave the opening remarks:

> All of us know that the pace of change is accelerating and that the Air Force has to engage the next generation of innovators, young scientists and engineers, and smart businesspeople to take us into our future. The Air Force has to engage with those innovators who want to help the warfighter to be able to defend our vital national interests…Here at AFWERX we are going to bring rapid contracting and intense and non-bureaucratic environment engagement and a lot of fun competitions to solve wicked hard problems to get innovation to the warfighter faster. (SECAF,2018)

Thus, christened by the SECAF and VPOTUS with an ambitious vision for the organization's role in igniting innovation within the Air Force, AFWERX Vegas became the first operational AFWERX innovation hub. Since then, the AFWERX physical and programmatic footprint has grown; they now have innovation hubs, or 'tech centers', in Austin, TX and in Washington, DC, and they execute numerous lines of effort which are all focused on improving USAF innovation practices, internally and externally. The AOT SBIR program is one of those lines of effort.

In partnership with the USAF SBIR team, AFWERX created the AOT program to experiment with SBIR investment and develop new ways of interacting with innovator. The SBIR program requires federal entities with research and development (R&D) thresholds over a certain amount to invest a portion of their R&D budgets to small businesses. Through AOT, AFWERX wanted to use the SBIR funds earmarked for small business to increase outreach to 'non-traditional' firms, shorten SBIR timelines, and decrease the bureaucratic costs of the SBIR

phases (Lt Col Scott, 2019). AOT goes about investing SBIR money in a radically different way. After approximately two years of experimenting with AOT, what can we say about the outcomes of these radically different processes? That is the motivating question for this research.

1.2 Problem Statement

From a both a taxpayer and warfighter perspective, the effectiveness of AOT outcomes compared with those of legacy SBIR, is not trivial matter. At a national level, the SBIR program represents a significant investment in domestic innovation ($2.2 billion in 2015), but like the larger DoD acquisition system, small business investment processes have largely remained unchanged since the 1980s when they were created (Small Business Administration, 2017). This research seeks to understand the effects of the changes AFWERX made through the Open Topic program using the legacy SBIR process as a baseline of comparison.

1.3 Research Focus

Comparison of AFWERX and legacy SBIR investment methods is the focus of this research. We began with a comparison of AFWERX and legacy strategies and processes. AOT solicits small firms that have technology or services (more or less) commercially proven and adaptable to USAF problem sets. Additionally, AOT facilitates an innovation process wherein firms are encouraged to seek out USAF customers with problems that can be solved using the firm's existing technology or services. Alternatively, legacy SBIR methods define specific problems which firms must respond to. After describing the nuts-and-bolts differences between AOT and legacy process, a comparison was made using a metric called commercialization.

From the perspective of the Small Business Administration (SBA) which creates the guidelines for the SBIR program, the main objective of the SBIR program is the commercialization of small businesses participating in program. Commercialization occurs when

a firm receives non-SBIR funding for a product or service it previously received SBIR funding to develop. This analysis compared the commercialization performance of AOT and legacy SBIR investment methods. While commercialization is the goal of the program overall, the USAF is primarily interested in the use of SBIR investments to net gains in military capability related to its specific mission. Therefore, the third area of comparison in this research considered the types of military capabilities in which AOT and legacy methods invest.

In the commercial sector, diversified firms actively select investment levels for their portfolio of products, business units, R&D, etc., in order to maximize profits. This process of portfolio allocation aligns firm resources with firm strategy. Although neither legacy SBIR nor AFWERX deliberately invest funds as a function of a capability portfolio, USAF investment into small business via the SBIR program is essentially an exercise in military portfolio allocation. Every SBIR contract awarded through the USAF is a choice (conscious or otherwise) which aligns warfighter resources to investments in warfighter capabilities. The third area of comparison looks at the AOT and legacy SBIR military capability portfolios (MCP) which are a byproduct of these SBIR contract choices. The last comparison area looks at the effectiveness of the AFWERX strategy which guides the placement of its physical offices.

AFWERX has collocated some of its offices (also called ‘tech centers’ or ‘front doors’) in regions of the country known for being bastions of innovation, to include Austin, Texas, and the Crystal City neighborhood of Arlington, Virginia, close to the Pentagon and DC. One assumption underpinning this collocation strategy is that establishing front doors in innovative regions will allow AFWERX to build connections with innovative firms in those regions that otherwise might not have been made. We might be able to observe whether the AFWERX Austin and AFWERX DC front doors catalyze SBIR participation in those regions by comparing AOT

regional participation proportions with those of legacy SBIR. The final comparison does just that; we tested the differences between the proportion of AOT firms headquartered out of TX and DC with the proportion of legacy SBIR firms headquartered out of TX and DC. These focus areas are codified in the research questions below.

1.4 Research Questions

These are four research questions addressed in this analysis.

***Research Question 01* - [RQ01] AFWERX vs Legacy SBIR: Processes**

> *How does AFWERX's SBIR investment process differ from legacy SBIR investment processes?*

***Research Question 02* - [RQ02] AFWERX vs Legacy SBIR: Commercialization**

> *What commercialization performance differences exist between AFWERX and legacy SBIR programs?*

***Research Question 03* - [RQ03] AFWERX vs Legacy SBIR: Military Capability**

> *What differences exist in the military capability portfolios generated by AFWERX and legacy SBIR?*

***Research Question 04* - [RQ04] AFWERX 'Tech Centers' and SBIR Participation Rates**

> *How do AFWERX innovation hubs located in technology clusters (e.g. AFWERX-Austin and AFWERX D.C.) effect regional SBIR program participation rates?*

1.5 Summary of the Literature Review Chapter

The literature review section provides a background on SBIR, related legacy SBIR process to concepts in innovation literature, describes AFWERX, and the Joint Capability Areas (JCA) taxonomy (RQ03), and explains the statistical test used in RQ02-RQ04 (Chi-square test).

1.6 Summary of the Methodology Chapter

The methodology section addresses the data and analytical steps taken in this research to answer RQ02 (pertaining to AFWERX Commercialization), RQ03 (pertaining to AFWERX & military capability outcomes), and RQ04 (pertaining to Tech clusters and regional SBIR

participation rates). Overall, this research completed phases of exploratory data analysis followed by basic statistical analysis to assure the significance of reported results. The main analytical tools used were a panel-of-raters methodology and 2x2 contingency table analysis. The panel-of-raters methodology was used to ensure interrater reliability of the assignments of SBIR contracts into military capability categories and the 2x2 contingency table analyses were used to find statistical differences between the characteristics of groups (AOT and legacy) within the larger SBIR population.

1.7 Summary of the Results Chapter

This section shows methodology results. For RQ02, we find that AFWERX has greater commercialization than the 8% Rask (2018) found for legacy SBIR investment processes. However, we caveat that finding by noting the ways in which commercialization metrics, under their legacy definitions, may not be valid measures of true commercialization for AFWERX. For RQ03, we find that the MCPs for AOT and traditionally managed SBIR investments are statistically different. Legacy SBIR is associated with higher investment in Force Application capabilities while AOT is associated with higher investment in Command & Control and Force Integration capabilities. For RQ04, we find evidence linking AFWERX tech centers with regional SBIR participation rates; AOT SBIR participation rates are statistically higher than those of legacy SBIR in the regions of TX and DC.

1.8 Limitations

The methodologies used in this research have limitations. In RQ01, we compared processes. A limitation related to RQ01 is the fact that AOT processes are still changing so inferences made from process differences may not be valid over time. RQ02 & RQ03, made use of a categorization schema whereby innovations were bucketed into categories. Efforts were

made to maximize the reliability of categorization, but there can still be a significant amount of ambiguity in coding JCAs. RQ02 – RQ04 made use of two-way(2x2) contingency table analysis as a tool to observe statistical differences between characteristics of AOT and legacy SBIR. An assumption of 2x2 analysis is that the *n* observed counts are a random sample from the population of interest (McClave, Benson, & Sinchich, 2012). For AOT, samples from RQ02 and RQ03 were random, but for RQ04, samples consisted of the entire set of AOT and legacy SBIR contracts from 2019 and 2016 respectively. In other words, the samples were large but one limitation of RQ04 is that the results may be explained by an exogenous variable related with the time period of each sample.

II. Chapter 2 - Literature Review

2.1.Chapter 2 Overview

AFWERX is an organization created by the USAF to be a catalyst for innovation. One of its lines of effort is called AFWERX Open Topic (AOT). AOT uses money the USAF budgets for small business via the SBIR program to adapt commercial technology to USAF needs. When technology solves USAF needs, this is an example of USAF innovation. The AOT has a novel approach for maximizing USAF innovation through investment in small business. The novelty of their approach stems from how different it is from what was the status quo approach to executing the SBIR program. This research refers to the status quo approach to USAF investment in small business "legacy SBIR*"*. The use of "status quo" here does not constitute a positive or a negative judgement; it merely indicates the state of affairs prior to AOT. This research is a comparison of AOT and legacy SBIR, and this chapter provides the background information necessary to understand the comparison.

The literature review section provides context for the questions asked in this research and for the methodologies used to address those questions. The first section of this section provides background on legacy SBIR. It is relevant to all research questions, but it is particularly relevant to the comparison of AOT and legacy processes in RQ01. Section two sets this research against the backdrop of innovation literature by describing two alternative perspectives on technological/innovation change: *technology push* and *demand pull*. In RQ01, we argue that AOT and legacy SBIR represent technology push and demand-pull processes, respectively. In section three, we provide background on AFWERX. Like section one, section three is relevant to all research questions, but it is particularly relevant to the comparison of AOT and legacy processes in RQ01. Section four provides background on the JCA taxonomy which defines

categories of military capability. It is most relevant to the methodology used for comparing military capability portfolios (MCP) in RQ03. Finally, section five provides background on the statistical method used in RQ02-RQ04 to test for independence between proportions of AOT and legacy SBIR characteristics. The Chi-Square test of independence was used to test independence between AOT and legacy SBIR for the characteristics of commercialization rates (RQ01), military capability portfolio (MCP) investment rates, and regional SBIR participation rates. Section four Here, part one begins with a brief history of the SBIR program.

2.2.SBIR Background

The SBIR program began as an experimental program for the National Science Foundation (NSF) in 1977 (SBA, 2017). It was created at the urging of small business upset with the status quo federal research landscape in which funding flowed either from the NSF to universities or from the DoD and NASA to large firms that were equipped to handle the complex demands of their customers (National Science Foundation). The success of the first round of SBIR recipients coupled with influence of the program's advocates led to the passage of the Small Business Innovation Development Act in1982 (SBA, 2017). With the passage of this act SBIR program was implemented government wide and implemented by the Small Business Administration (SBA). Federal agencies which received more than a certain threshold of R&D budget were required to obligate a percentage of that budget for SBIR awards to small businesses. Thresholds and required percentages have changed over time, but as of 2017, they were $100M and 3.2%, respectively (SBA, 2017).

2.3.STTR

One type of federal small business investment which is closely associated with SBIR and which has not yet been mentioned is the called the Small Business Technology Transfer (STTR)

program. The unique feature of the STTR program is the requirement for a small business to formally partner with a research institution in the hopes that this partnership will help bridge the gap between the performance of fundamental scientific research and the commercialization of the resulting innovations. While AFWERX is also involved in STTR investments, STTR is not the focus of this analysis.

2.4.Legacy Methods of SBIR Program Implementation

The mission of the SBIR program, as defined by the SBA (2019), 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". Congressman Roland Tibbetts, the 'Father of the SBIR program' and its fiercest advocate, envisioned a three-phased approach to accomplishing the SBIR mission. Since 1982, the operation of the SBIR program, to include the three phased approach, has gone more or less unchanged. A discussion of those three phases follows.

Feasibility, prototype development, and commercialization are the foci of Phases I through III, respectively. The objective of Phase I of SBIR/STTR programs is to determine the scientific and technical merit, feasibility, and commercial potential. Phase II is concerned with refinement, through R&D, of the efforts initiated in Phase I and Phase II funding is based off results from Phase I. Phase III refers to work that is derived from, extends, or completes an effort made through SBIR/STTR-funded Phase I or II R&D but is funded by sources other than the SBIR/STTR Programs. Otherwise stated, Phase III does not involve a contractual arrangement between the firm and a SBIR entity. Table 1 provides a description of the objective, associated funding levels, and timelines for the three SBIR phases.

Table 1: SBIR/STTR Phases, Funding, and Timelines

Phase	Funding		Timelines (months)	
	Minimum	**Maximum**	**Minimum**	**Maximum**
Phase I - Feasibility	$150,000	$225,000	6	12
Phase II – Cont'd R&D	$750,000	$1,500,000	24 (2 years)	
Phase III - Commercialization	Not applicable. Funding and timelines of business commercialization are independent of SBIR/STTR Program.			

Small businesses are placed on contract for a Phase I or II after responding to a 'topic' from a government solicitation for proposals. Topics are textual descriptions of the needs or interest areas of the soliciting federal agency. Approximately three times a year, bundles of topics are released to the public through 'broad area announcements' (BAAs) as part of the government SBIR solicitation process. In the context of the innovation literature, the legacy method of SBIR solicitation just described qualifies as a market-pull process; the user of the innovation (government) is requesting (or pulling) the innovation from the market to solve a user specified problem.

2.5.Sources of Innovation: Technology Push vs Demand-Pull

This section frames legacy SBIR against the technology push versus demand-pull dichotomy popular within innovation literature, and it is relevant to this research for two main reasons. First, by juxtaposing legacy SBIR processes with the sentiments of recent literature on the sources of innovation, we were able to identify a need for USAF SBIR operations to incorporate more technology push process logic within their SBIR investment strategy. This set the scene for discussion of AFWERX, the AOT program, and whether/how they play a role in addressing this need. Second, this section introduces a framework which helped in the

comparison of these two USAF SBIR methods and informed our theoretical understanding of how the differences in processes noted in RQ01 might translate into differences in outcomes.

Since the 1950s, scholars researching the economics of technological change have tended to take either a technology-centric or a demand-centric perspective on the sources of innovation (Teece, Pisano, & Shuen, 1997; Christensen & Bower, 1996; Di Stefano, Gambardella, & Verona, 2012). The technology-push, now denoted 'tech-push', perspective has focused on the key role of science and technology while the demand-pull (also called market pull) perspective has focused on the role of the end market (or users) in determining the performance of innovation (Di Stefano, Gambardella, & Verona, 2012). Figure 1 compares tech-push and market pull processes. Notice how, for market pull, an "expressed market need" triggers the execution of other steps in the process.

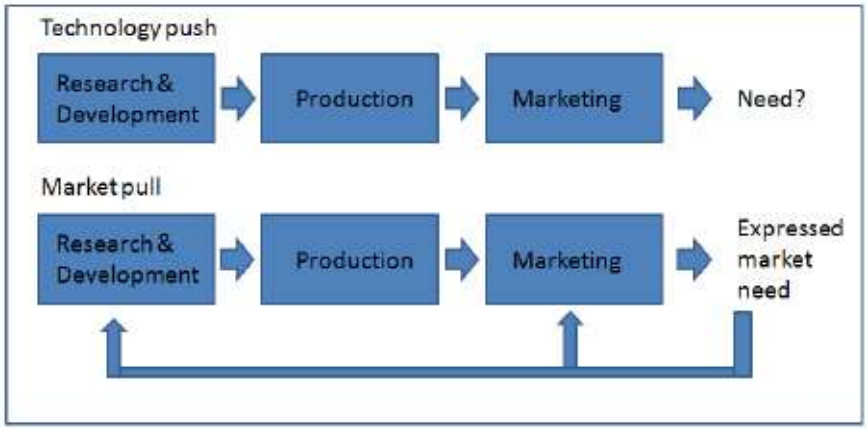

Figure 1: Technology Push vs Market (or demand) Pull (Isoherranen & Kess, 2011)

Although it can be technically complicated to distinguish tech-push from a demand-push situation (Mowery & Rosenberg, 1979), we view the standard legacy SBIR process as an example of demand-pull logic. Within this traditional approach to SBIR investment, innovation is sort of "called forth" or "triggered" (Mowery & Rosenberg, 1979) via a demand signal. This "triggering" of innovation by a demand signal is in line with the demand-pull perspective on how

innovation occurs. Demand-pull scenarios can be colloquially referred to as “Problems seeking solutions”. When a problem seeking a specific solution finds that solution, innovation has occurred as a byproduct of a demand-pull logic. Similarly, innovations born out of legacy SBIR are a byproduct of a demand-pull logic; the USAF defines specific technological problems in the form of legacy SBIR topics then creates a demand signal via the publication of BAAs.

At the same time legacy SBIR innovation processes seem firmly in the demand-pull camp, innovation research is moving away from a linear technology-or-demand dichotomy in favor of an interactive model that highlights the dual importance of both innovation sources (Di Stefano et al., 2012). According to Di Stefano et al. (2012), there is a growing consensus on the mutual dependence of technology and demand “with an emphasis on technology…as the ultimate source for the vast majority of technological innovation”. Further, as part of this consensus, Di Stefano et al. (2012) noted that demand is considered “the best companion [to technology] to drive innovation in the right economic and institutional directions”. If our characterization of legacy SBIR (as a demand-pull approach) is correct, there is dissonance between that demand-centric legacy strategy and current academic literature which speaks of the primacy of technology (albeit, guided by demand towards the right ends) as the main source of innovation.

One interpretation of recent innovation literature, as it applies to this research, is that an imbalance existed in the USAF’s strategy to adopting innovation via the SBIR program due to the near-exclusive use of demand-pull logic and minimal use of tech-push logic in the formation of legacy SBIR’s innovation processes. In a tech-push scenario, innovation occurs when a solution (technology or service) seeks a problem. With the creation of AFWERX, and

subsequently, through the creation of the Open Topic program, the USAF SBIR is seeing an increase in SBIR investment processes that utilize tech-push logic.

In this section, we looked at legacy SBIR processes through the analytical window of innovation literature, in which tech-push and demand-push are the seen as the primary sources of innovation. By juxtaposing the idea that legacy SBIR processes mostly use a demand-pull innovation logic with the fact that recent innovation literature – while recognizing the important role demand forces play in steering innovation –views technology as the main source of innovations, we highlighted a need for the USAF to incorporate technology push process logic as part of their SBIR investment strategy; this sets up the discussion on AFWERX and AOT in the section that follows. Additionally, we used this tech-push vs demand-pull framework to help with comparison between AOT and legacy SBIR and we draw on it to help explain the results of our methodology

2.6.AFWERX

This section provides background on AFWERX. This background informs our understanding of the research questions and results of this research. In the first part of this section, we speak to the challenges disruptive technologies pose to firms and to the DoD. In the second part, we describe what the AFWERX Charter says the organization ought to be doing.

One of the questions stemming from long-debated research on disruptive technology is whether incumbent firms will inevitably fail to seize radical innovation opportunities on account of organizational inertia and managerial focus on target markets to the exclusion of innovative pursuits (Di Stefano, Gambardella, & Verona, 2012). In the commercial sector, an incumbent firm is a well-established company. The threats posed by discontinuous technological change to the incumbent firm have repeatedly been the subject of scholarly research (Clark, 2005; Hannan

& Freeman, 1977; Henderson & Clark, 1990; Levinthal, 1992; Teece, Pisano, & Shuen, 1997). Clark (2005) defines discontinuous change as "external change requiring internal adaption along a path that is nonlinear relative to a firm's traditional innovation trajectory". Teece et al. (1997, p. 520) highlight the fact that incumbent firms, unlike new entrants, are burdened by their status quo organizational processes which were optimized for conventional products/services and can't support the new technology. The impediments to innovation that plague the incumbent firm, also burden the DoD and its service components. The USAF created AFWERX to bypass impediments to innovation brought on by organizational inertia and to respond/adapt to disruptive technology.

AFWERX was created in 2017 to serve as a catalyst of innovation for the USAF. Specifically, AFWERX was given the following mission statement in its 2018 charter:

> AFWERX will serve as a catalyst to innovate, integrate, and implement creative and disruptive technology options derived from mutually beneficial relationships with industry, academia, and non-traditional contributors to effect transformative opportunities for the Air Force, including fostering agile and non-traditional acquisition. (SECAF, 2018)

As part of declaration of the mission, the charter also defined the streams of effort AFWERX is to execute to accomplish the mission. The first line of effort calls on AFWERX to function as interface between various entities to bolster USAF tech and/or the organizational competencies that help secure it:

> 2.1 Function as an interface between the Air Force, entrepreneurs, start-up firms, commercial entities, non-profit organizations, and academic institutions throughout the United States to increase Air Force access to leading-edge technologies, talents, and innovation processes. (SECAF, 2018)

The second line of effort calls on AFWERX to play the role of the AF's talent scout for commercial firms and technology:

> 2.2. Scout for promising commercial technology and serve as a catalyst to transition it into the Air Force to ensure battlespace advantage for future warfighters, as well as pioneer procurement and acquisition pathways for start-up firms and non-traditional entrants to the defense industry.

The third line of effort highlights some of the tools available to AFWERX and asks them to build the interest of the firms within the innovative commercial ecosystems they work out of:

> 2.3. Use research and development agreements, contracts, prize competitions, public-private partnerships, and other tools and forms of acquisition and assistance to solve Air Force innovation challenges, while helping grow the circle of entrepreneurs and investors interested in the technical challenges of maintaining U.S. security

In summary, the AFWERX Charter calls on AFWERX to embody a new USAF core competency focused around, and in no order of priority, (1) sensing the external tech landscape, (2) facilitating adoption of dual-use commercial tech, and (3) building the size and excitement of USAF-Commercial networks, and (4) solve USAF innovation problems. Numbered items from the preceding sentence do not map one-to-one with the quotes from the charter above. Instead, they are a crosscutting attempt to capture the main themes from those quotes.

2.7.Military Capability Portfolio Segmentation

This section provides context for the RQ03 methodology within which a comparison was made between AOT and legacy SBIR MCPs. The first part of this section addresses how SBIR investments are akin to commercial portfolio allocation problems. Part two provides background on JCAs and how they were used previously to conduct a capability-based segmentation of a legacy SBIR portfolio.

In the commercial sector, diversified firms actively select investment levels for their portfolio of products, business units, R&D, etc., in order to maximize profits. This process of portfolio allocation aligns firm resources with firm strategy. USAF investment into small business is an exercise in military portfolio allocation. Every SBIR contract awarded is a choice

(conscious or otherwise) which aligns warfighter resources to warfighter capabilities. At present, neither legacy SBIR nor AFWERX deliberately invest funds as a function of a capability portfolio. The military capability-based portfolio segmentation considered in RQ03 is ex post, based on the actual investment choices made by both processes. JCAs, described next, were used to group and analyze SBIR investment choices as a part of RQ03

JCA's represent capabilities that are required or desired within the DoD (Rask, Commercialization Analysis for SBIR Funded Technologies, 2018). The JCAs taxonomy was created by the DoD Joint Staff in 2005 to improve communication between the military services and therefore, joint warfighting efficiency, by codifying a common (and exhaustive) lexicon of military capabilities. There have been subsequent changes to the JCA taxonomy, but in every iteration, individual JCAs have two components. The first is a textual description of a military capability and the second is a succinct title which represents the described capability. There are eight top-level, or 'tier-1', JCAs; there titles are (1) *Force Integration* (FI), (2) *Battlespace Awareness*, (3) *Force Application* (FA), (4) *Logistics*, (5) *Command & Control* (C2), *Communications & Computers*, (6) *Protection*, and (7) *Corporate Management & Support*. Decomposed from each of the eight tier-1 JCAs are sub JCAs which can also be decomposed (all the way down to tier-4). The further a tier-1 JCA is decomposed, the more specific the sub-JCAs become. For example, (3) FA is described as "The ability to integrate maneuver and kinetic, electromagnetic, and informational fires to gain a position of advantage and/or create lethal or nonlethal effects on designated targets". FA contains (3.2) *Fires,* which contains (3.2.3) *Information,* and (3.2.3) *Information* is defined as "The ability to create effects on humans and automated systems in the information environment". The JCA taxonomy was by Rask (2018) to segment a sample of legacy SBIR topics to assist in a capability-based analysis.

As part of his commercialization analysis of a sample of legacy USAF SBIR topics, Rask (2018) identified a lack of a tailored capability-driven taxonomy for DoD SBIR programs. After identifying that need, Rask determined that the DoD's JCA taxonomy provided a viable taxonomy for USAF SBIR programs. With a taxonomy chosen, Rask found that using a panel of raters as the JCA assignment methodology was valid with 97.4% agreement among the panel for JCA assignment. He proceeded to assign a random sample of 202 USAF SBIR topics from fiscal year (FY) 2015 to FY 2018 into JCAs using the panel of raters approach (2018). As a result, the first USAF SBIR MCP was created. RQ03 of this research utilized Rask's (2018) panel of raters JCA assignment methodology to assign AOT innovations into JCAs. This enabled an "apples-to-apples" comparison of the resulting AOT MCP with Rask's (2018) legacy SBIR MCP, henceforth just 'legacy MCP', recently mentioned. To test for statistical differences between the legacy MCP and the AOT MCP, a Chi-Square test of independence was used as part of a two-way (2x2) contingency table analysis.

2.8.Chi-Square test of Independence and 2x2 Contingency Analysis

This section supplements the methodology section by providing a brief explanation of contingency tables and how they were used in this research. Contingency tables are used in categorical data analysis to test for a relationship between two qualitative variables and as a test of proportions (Terpening, 2011). Each cell in a contingency table represents the count or frequency of observations meeting certain criteria (which are specified by the cells row and column). When there are two categorical variables which each have to possible levels (outcomes), a two-way, or 2x2, contingency table is used, and the parameter of interest is a proportion. The Chi-square test was used in this research to test independence between AOT and legacy SBIR for the characteristics of commercialization rates (RQ02), military capability

portfolio (MCP) investment rates (RQ03), and regional SBIR participation rates (RQ04). These tests were conducted JMP, a statistical software, using the 'Fit Y by X' function.

Hypothesis testing for independence in 2x2 contingency tables is done with the chi-square distribution. It is frequently called Pearson's Chi-square test for independence, but henceforth, it is just called the Chi-square test. The general form of a 2x2 table analysis null hypothesis is that the two variables are independent, and the alternative hypothesis is that the two variables are dependent (McClave et al., 2012; Terpening, 2011). The Chi-square value for value for contingency table is based on the deviation of the actual frequencies from the expected frequencies. The equation for the test statistic is $\chi^2 = \sum \frac{(f_o - f_e)^2}{f_e}$ where $f_o \; and \; f_e$ are the observed (count) and expected frequencies respectively and the summation is over all cells in a table.

The test for two population proportion, which uses the Z test and the normal distribution, could have also been used to detect statistical differences our categorical variables. In fact, the results for a Pearson chi-square test run via a two-way contingency table analysis, ceteris paribus, are "entirely equivalent" (Terpening, 2011) to results from a test for two population proportions (McClave, Benson, & Sinchich, 2012). After all, if you square the Z value from a Z test, it is equal to the Pearson Chi-square value from a 2x2 contingency table analysis. The benefit of conducting contingency table analysis is that JMP automatically generates mosaic plots, odds ratios, and the Fisher Exact test as part of the 2x2 table results. Mosaic plots provide a graphical representation of association between two variables, odds ratios measure the magnitude of association between two categorical variables, and Fisher's Exact test is ideal when cell frequencies are less than five.

There are two conditions required for a valid Chi-square test in a 2x2 contingency table (McClave, Benson, & Sinchich, 2012). These conditions are shown in Table 2.

Table 2: Conditions Required for a Valid χ^2 with Contingency Tables (McClave et al., 2012)

#	**Condition**
1	The *n* observed counts are a random sample from the population of interest. We may then consider this to be a multinomial experiment with r x c possible outcomes.
2	The same size, *n,* will be equal to 5 or more.

We discuss these conditions in the Results chapter.

III. Methodology

3.1. Introduction

This chapter details the data and methodologies used to answer RQ02 - RQ04. For RQ02, we used presence of government matching funds for a company in the AFWERX data set as evidence of commercialization, calculating an aggregate AOT commercialization rate and a commercialization rate by JCA area. For RQ03, we segmented a randomly sample of 60 companies into JCA's then used contingency analysis to test whether and how AFWERX capability investments may differ from those of legacy SBIR. In RQ04 we conducted a 2x2 contingency table analysis to test for independence between two categorical variables ('SBIR ORG' and SBIR participation rates for TX and DC).

3.2. Data Collection

There were three sets of data used for this research. The first was an AFWERX-provided internal spreadsheet. It is an ideal source of data for a study on Open Topic performance because it is a near-complete administrative and financial record of the companies involved with phase I and II Open Topics since the program began. The second source of data comes from Rask (2018) by way of the Air Force Research Lab (AFRL) Small Business office (AFRL SB). It was used to as a baseline of comparison for AFWERX in the areas of commercialization rates (RQ02) and military capability portfolio allocations (RQ03). The third source of data came from the SBIR award database on the SBIR website. It was used to compare AFWERX regional investment amounts to those of legacy SBIR.

3.3. AFWERX Dataset

Table 3 shows relevant information from the AFWERX dataset. Each row contains attributes (company name, etc.) of a firm which received money from AFWERX. The attributes

leveraged in this analysis are the three company statements and the information on matched-funding by non-AFWERX government entities. This data supported joint capability area (JCA) mapping and commercialization analysis respectively.

Table 3: AFWERX Dataset

Company Attribute (Data Element)	Attribute Description	Attribute Use
Problem Statement	A company's written statement, required for their Open Topic proposal package, which describes a DoD problem which their technology/service might help to address.	Company statements attributes are categorized by JCA using the panel of raters technique (Rask, 2019). JCA mapping provides a means to segment the AFWERX innovation portfolio by military capability provided. It also allows for a comparison with baseline SBIR capability investments.
Proposed Solution Statement	A company's written statement, required for their Open Topic proposal package, which describes their proposed solution to the DoD problem which they define in their Problem/Opportunity statement.	
Impact Statement	A company's written statement, required for their Open Topic proposal package, which describes the impact to the DoD of implementing the solution the company describes within the Proposed Solution statement.	
P2 Govt. Matching "GovMatch"	"P2 Govt. Matching" or "GovMatch", contains the dollar amount given to the company by a non-AFWERX government source.	GovMatch is used to create a variable to capture the commercialization rate of Open Topic companies. Commercialization rate is the established metric to capture the impact of SBIR investments.
Contract/Admin Attributes	This encompasses multiple company attributes which are all administrative and contractual in nature, including USAF Topic #, contract #, contract type, company name, Open Topic Cohort, etc.	Contract/Admin attributes are used to gauge the accuracy of the AFWERX spreadsheet by crosschecking it against SBIR award information pulled from the SBIR.gov website. More importantly, these attributes enabled the creation of an incumbency variable for each company which shows how many previous SBIR contracts they were a part of.

3.3.1. SBIR.gov Awards Dataset (SAD)

The SBIR.gov Awards Dataset (SAD) is a spreadsheet created from the SBIR Award database found on the SBIR.gov website. It supported analysis for RQ04. This dataset provided a list of all companies participating in SBIR in 2016 along with their state of headquarters.

3.4.JCA Categorization

3.4.1. Overview

This section describes how a panel of raters used company statements in the AFWERX data set to segment company proposals into JCAs and how this segmentation may enable insights into AOT commercialization performance (RQ02) and on the types of military capabilities AFWERX invests in (RQ03). A similar segmentation was accomplished with a randomly selected sample of legacy SBIR data from 2015 to 2018 by Rask (2018). This analysis follows the same methodology of JCA categorization outlined in Rask (2018). Next, a background of JCAs is provided.

The JCA coding methodology began by taking a random sample of 202 companies from the AFWERX dataset. A panel of raters then assigned (or 'coded') JCAs for each of those companies. There are three main steps to mapping which are iterated at each of these mapping sessions. They are reading, discussion, and assignment. During the reading phase, the panel of raters look over a specific AFWERX company's statements (problem, solution, and impact). Next, in the discussion phase, raters discuss the company statements to ensure a common understanding of the innovation in question and the functional area it seems to be targeting. In the assignment phase, raters propose JCA's which might be relevant to the company's proposal, debate the appropriateness the proposed JCA's based on the available information, then assign JCA's. In the event of divergent opinions on the applicability of a JCA/JCAs to a company's

innovation or if there appear to be multiple applicable JCA's, a company's proposal can be assigned a primary, secondary, and tertiary JCA.

Figure 2 (Rask, Commercialization Analysis for SBIR Funded Technologies, 2018) shows the flow of a JCA rating session.

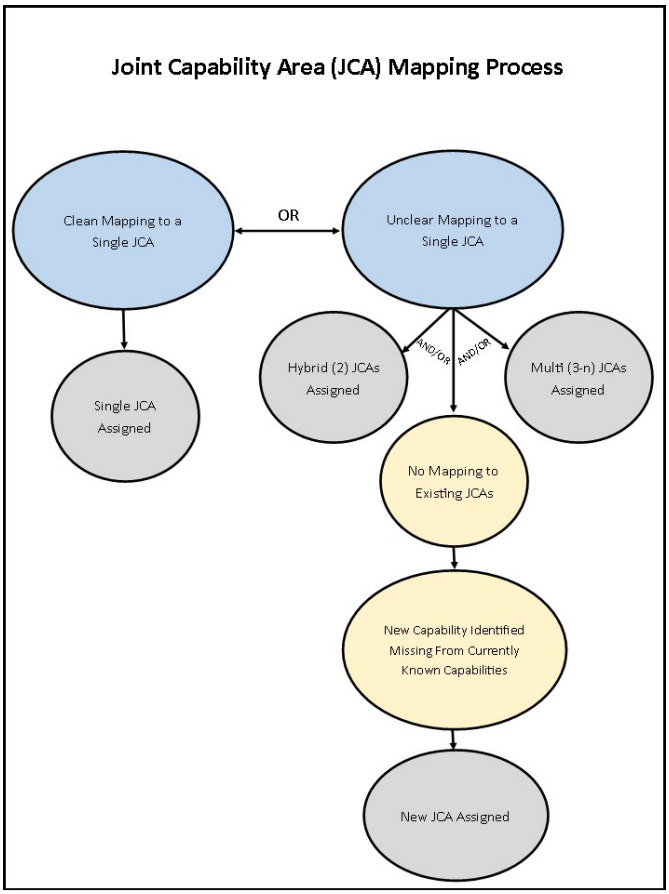

Figure 2: JCA Panel of Raters Flow Chart

With a random sample of AFWERX companies coded into JCAs, we were able to take a portfolio view of AFWERX commercialization performance (RQ02), observe differences between the types of military capabilities each investment processes makes (RQ03), and set the groundwork for future research to explore ways industry and commercial technology might map to JCAs. In the subsequent sections, we outline the methodologies used to answer each research question.

3.5.RQ02 – AFWERX vs Legacy: Commercialization

Commercialization is an established metric for SBIR projects. It assesses whether a project transitions from SBIR seed funds to other sources of funding either in the government or the commercial sector. The purpose of SBIR is the stimulation and strengthening of small businesses, whether a given federal agency benefits from the technology is secondary. Success is counted when the innovation transitions from the SBIR seed funds.

As discussed in Chapter 2, AFWERX has added processes to seek out early government engagement. AFWERX actively fosters matching between open topic innovators and government customers. One measure of government customer interest is matching funds. Matching funds are introduced in what is traditionally Phase II of the SBIR process. This government matching funding is tracked within the AFWERX data set.

The presence of non-SBIR government matching was used to create a dummy variable, 'DV_Commercialization', for each firm in the dataset. Non-SBIR government matching greater than zero received a DV_Commercialization value of one, otherwise a value of zero. Aggregate commercialization rates were calculated as the count of non-zero DV_Commercialization firms over the total number of firms in the set. Capability area commercialization rates were calculated in a similar fashion. Through establishing portfolio and capability level commercialization rates a direct comparison to the historic SBIR performance baseline is possible.

3.6.RQ03 – AFWERX vs Legacy: Military Capability

A dichotomous variable called 'SBIR ORG' was created in both the AOT and the legacy SBIR data sets. The two values for 'SBIR ORG' were 'AFWERX' and 'Legacy'. Next, we created dummy variables for each of the JCA levels in both SBIR data sets, now denoted as 'JCA X'. After creating SBIR ORG and dummy variables for each JCA level (1 – 8) for both SBIR

data sets, we created a dataset that merged the newly created variables. Each variable in the newly created data set has exactly two levels which enabled construction of a special type of contingency table called a two by two table (2x2). This enabled calculation of odds ratios. which measure the magnitude of association between two qualitative variables with two levels. With the data set in place, we conducted the contingency analysis. The hypotheses tested in the contingency analysis were formulated as

$$H_0: \pi_{AOT\_JCA\,x} = \pi_{Legacy\_JCA\,x}$$
$$H_A: \pi_{AOT\_JCA\,x} \neq \pi_{Legacy\_JCA\,x}$$

where $\pi_{Legacy\_JCA\,x}$ and $\pi_{AOT\_JCA\,x}$ are the investment proportions for JCA X (1-8) for legacy and AFWERX SBIR respectively. The hypothesis tests were conducted at an alpha of 0.1. After running the Chi-square test on JCA X (for each level) and SBIR ORG, we calculated the odds ratios for JCAs.

3.7.RQ04 AFWERX vs Legacy: Regional Response Rates

AFWERX has made a deliberate choice to locate its front doors in proximity to known tech clusters. RQ04 considers whether there is a difference in regional investments in the data set. We are looking for statistical relationships between the presence of AFWERX technical centers and that the SBIR participation rate where that technical center is located. AFWERX was created in 2017. Prior to that, there weren't any AFWERX innovation hubs in the District of Columbia (DC) or Texas (TX). During that pre-AFWERX period, firms from DC and TX participated in SBIR at a certain rate for legacy SBIR. If AFWERX SBIR participation rates in those two regions are different than the rates for legacy SBIR, this is evidence of regional effects on SBIR participation rates. Contingency analysis was used to test for regional effects.

The data used in this contingency analysis consisted of all AFWERX SBIR firms in 2019 and all legacy SBIR firms in 2016. Participating firms must provide descriptive information, such as the state of their headquarters, in order to get on contract. For each firm in the dataset, there's a categorical label for their state and the SBIR process they used. Prior to running the analysis, a dummy variable for Texas, 'DV_Texas', was created from the state variable (if 'state' = 'Texas', 'Texas', else '0'). A test for independence of proportions between 'DV_Texas' and 'SBIR Process' was conducted. Finally, because each categorical variable had only two possible outcomes each, we were able to find the odds ratios.

3.8.Methodology Conclusion

This chapter detailed the data and methodologies used to answer RQ02 - RQ04. For RQ02, we used presence of government matching funds for a company in the AFWERX data set as evidence of commercialization, calculating an aggregate AOT commercialization rate and a commercialization rate by JCA area. For RQ03, we segmented a randomly sample of 60 companies into JCA's then used contingency analysis to test whether and how AFWERX capability investments differ from those of legacy SBIR. As in RQ03, in RQ04 we conducted a 2x2 contingency table analysis to test for independence between two categorical variables ('SBIR ORG' and SBIR participation rates for TX and DC). The next chapter shows results from these methodologies.

IV. Chapter 4 - Results

4.1. Section Overview

This section shows the results for RQ01 – RQ04. Results for RQ01 highlight differences in the AOT and legacy innovation processes. Results for RQ02 show an AOT commercialization rate of 37.4%. For RQ03, there are statistically significant differences between the military investment patterns of AOT and legacy SBIR. The results of RQ04 show statistically significant differences between SBIR participation rates in TX and in DC; in both cases, AOT has a higher proportion of participation.

4.2. Results for RQ01 - Processes

AOT and legacy SBIR processes differ in many ways, but four stand out above the rest. First, unlike legacy SBIR, AOT SBIR solicitations are open to the entire spectrum of firms and innovations which represents a shift from a pull innovation model to a push; the market is pushing its offerings to the customer. The second major difference is the number and size of awards given by AFWERX; legacy SBIR gives less awards with greater amounts. The third difference we noted was that AFWERX SBIR solicits firms and technologies which are already commercially proven (or at least viable) and which have the potential to be adapted to USAF needs (dual-use); legacy SBIR, however, has the potential to invest in technologies much earlier, perhaps as a first entrant, when technical maturity is low and market synergies non-existent.

The last main difference we'll address is AFWERX's collocation strategy; they've built tech centers or innovation hubs in NV, TX, and in DC. The TX and DC tech centers are in regions widely known for being tech clusters. Tech clusters are regions with high densities of related industry (Kerr & Robert-Nicoud, 2019). In RQ04, we look for empirical evidence that

this collocation strategy results in higher participation rates from the tech cluster regions with innovation hubs.

4.3.Results for RQ02 - AFWERX vs Legacy SBIR: Commercialization

Of the 202 companies sampled, 55 received non SBIR government funding, or a commercialization rate of 37.4%. This is significantly higher than the 7.8% Rask found for legacy SBIR. That said, use of commercialization metrics to compare Open Topic with legacy SBIR is problematic. Open Topic researches the feasibility of adapting non-defense commercial solutions to Air Force needs; their ideal technology is already commercialized or close to it. Commercialization metrics are tracked to help SBIR decision makers understand whether and how SBIR investments help small firms develop. Commercialization success prior to SBIR participations increases the difficulty of distinguishing between SBIR investment effects and exogenous effects as far as commercialization outcomes are concerned.

4.4.Results for RQ03 - AFWERX vs Legacy SBIR: Military Capability

AFWERX and AFRL SBIR programs have different JCA portfolios. Table 4 shows the areas of greatest difference between the two organizations highlighted in the darkest shades of blue:

Table 4: JCA Portfolio Allocations for AOT & Legacy SBIR

#	Joint Capability Areas	Legacy Count | %		AFWERX Count | %		% Difference
1	Force Integration	3	1.3%	9	14.8%	13.4%
2	Battlespace Awareness	31	13.8%	9	14.8%	1.0%
3	Force Application	55	24.4%	1	1.6%	22.8%
4	Logistics	49	21.8%	16	26.2%	4.5%
5	Command & Control	6	2.7%	9	14.8%	12.1%
6	Communications & Computers	29	12.9%	6	9.8%	3.1%
7	Protection	14	6.2%	2	3.3%	2.9%
8	Corporate Management & Support	38	16.9%	9	14.8%	2.1%

Legacy SBIR investments into Force Application, "the ability to integrate maneuver and kinetic, electromagnetic, and informational fires to gain a position of advantage and/or create lethal or nonlethal effects on designated targets", is 23% higher than for AFWERX. On the other hand, AFWERX's investments into Force Integration and Command & Control, which are defined as "The ability to establish, develop, and maintain a mission ready Joint Force and build relationships with foreign and domestic partners" and "The ability to exercise authority and direction by a properly designated commander or decision maker over assigned and attached forces and resources in the accomplishment of the mission", are 13% and 12% higher respectively. The populations of investments differed in size, while the differences in proportion were large a test for the significance of that difference in the populations was completed (method reference here). The following hypotheses were tested:

$$H_0: \pi_{AOT\_JCA\,x} = \pi_{Legacy\_JCA\,x}$$
$$H_A: \pi_{AOT\_JCA\,x} \neq \pi_{Legacy\_JCA\,x}$$

Where $\pi_{AOT\_JCA\,x}$ and $\pi_{Legacy\_JCA\,x}$ are the proportions of projects coded for JCA X (Force Application, Force Integration, and Command and Control) for AFWERX and legacy SBIR respectively. Table 5 shows the results of statistical tests for the Chi-square test

Table 5: RQ03 Results of Chi-square Test – AOT & Legacy SBIR JCAs

JCA	P-value	Odds Ratio# (Dominant Org)
1. Force Integration	< 0.0001	12.8 (AOT)
3. Force Application	< 0.0001	19.4 (Legacy)
5. Command and Control	0.0002	14.8 (AOT)

The probability values associated with the Pearson test are highly significant for these three JCAs leading to a rejection of the null hypotheses; AOT and legacy SBIR are statistically different. The Chi-Square test for independence used here for contingency analysis tests for an association but it does not provide a measure of the magnitude of association. The odds ratio is a measure of the magnitude of an association. Hypothetically speaking, if all that was known about a SBIR contract was that it was given by AFWERX Open Topic, that contract is 12.8 times more likely to be Force Integration coded and 14.8 times more likely to be Command and Control coded than if the SBIR contract was given under a legacy SBIR process. If all that was known about a SBIR contract was that it was given under a legacy SBIR process, it would be 19.4 times more likely to be Force Application coded than if it were given under AOT. These differing JCA portfolios imply aggregate differences in the military application each SBIR method (org) favors. What explains these differences?

4.5.Results for RQ04 - AFWERX 'Tech Centers' and SBIR Participation Rates

How do AFWERX innovation hubs located in technology clusters (e.g. AFWERX-Austin and AFWERX D.C.) effect regional SBIR program participation rates?

4.5.1. Overview of RQ04 Results

This section presents the results of RQ04. This research question builds off the results of RQ01 and RQ03. In RQ01, we compared the AOT versus legacy SBIR investment processes. Through that comparison, we found the two processes to be substantially different. In the RQ03 methodology, we used a disciplined approach to bin AFWERX and legacy SBIR investments into categories of military capability called JCAs. As a result of this categorization, we found highly statistically significant differences (p-value <0.01) in the JCA Portfolios of these two approaches for three categories: Force Integration, Force Application, and Command and

Control. With RQ04, we explore associations between the process differences highlighted with RQ01 and military capability investment differences highlighted in RQ03.

AFWERX's unique geographic and market strategies may explain why their distribution of SBIR investments into military capability areas differs from that of legacy SBIR. We explore quantitative and observational evidence that geographic and/or market forces influence JCA Portfolio allocations in the sections that follow.

First, we consider geographic factors by asking the question "Does the presence of an AFWERX campus increase SBIR participation in the region surrounding that campus and would this increase explain differences between their JCA portfolios?". To answer this question, we explore three relationships: 1) AFWERX campus location & regional SBIR participation rates, 2) company headquarters location and company innovation type, and 3) commercial industrial/technological areas (IT, finance, etc.) and the joint capability areas (JCAs). Later on, we refer to these three relationships as premises which must be proven to show geo factors exist.

Next, we look at market forces by asking the question "Does AFWER's push vs AFRL SBIR's pull approach to innovation help explain differences in their JCA portfolios?". As implied in the question and addressed in the literature review section, legacy SBIR employs a market pull style of innovation (a problem seeking a solution) while AFWERX uses a technology push (a solution seeking an application).

Table 6: Organization of Section

Error! Reference source not found. **SUBSECTION**	**FOCUS QUESTION**
Overall Inquiry (RQ04 Refined)	Can geographic factors and/or market forces unique to AFWERX or legacy SBIR help explain their different JCA Portfolio Allocations?
Geographic Factors	Do AFWERX campus locations (DC, Austin, etc.) influence company SBIR participation rates from those campus regions?
Market Forces	Does AFWERX's emphasis on tech push (solutions looking for a

	customer) influence

In the Literature Review, we described AFWERX's strategy of collocation AFWERX. AFWERX builds campuses near innovative ecosystems for the stated purpose of attracting innovators from those locations. This section shows the results of our exploration into the ways geographic features (such as AFWERX's collocation strategy) might influence the distribution of SBIR investments across the JCA spectrum of military capability.

There are three premises which, if each are proven likely, support the conclusion that geographic factors predict JCA portfolio allocations and therefore explain some of the differences between AFWERX and legacy SBIR capability portfolios. Results in this section are presented as evidence for, against, or indeterminate for each of these premises.

The first premise, illustrated in Figure 3, is that the presence of an AFWERX campus in a tech cluster increases the rate of SBIR participation in that region.

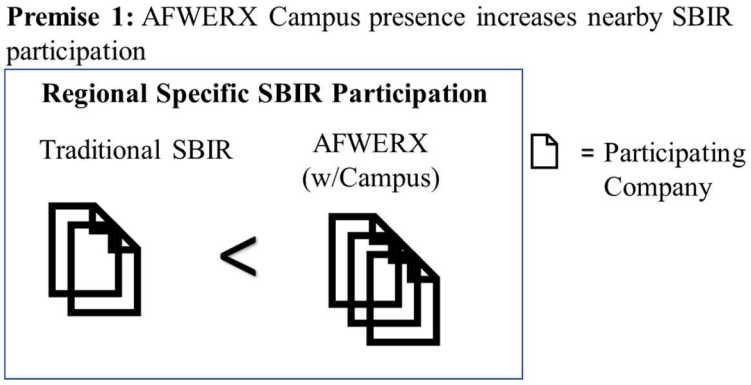

Figure 3: Premise 1

The second premise, illustrated in Figure 4, is that the types of technology a small business leverages for a SBIR arrangement are predicted by that companies' technological and industrial characteristics. For example, if a region's industry is dominated by the Information Technology

(IT) industry (i.e. they are an IT tech cluster), premise 2 says SBIR participants from this region are more likely to be involved in IT related innovations that other types.

Premise 2: Company proposals reflect characteristics of their region's industrial specialties

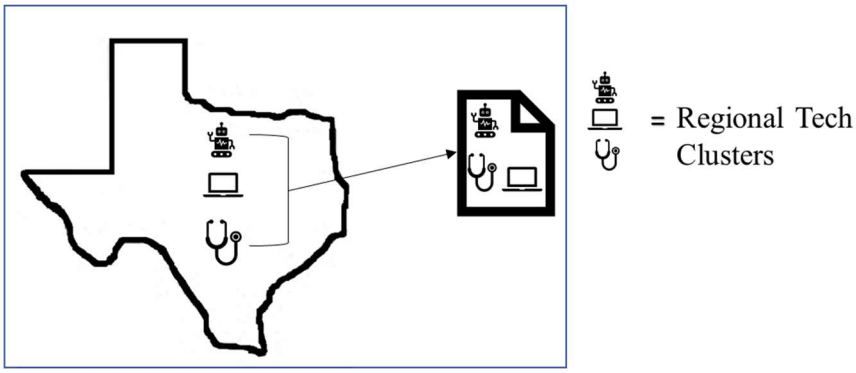

Figure 4: Premise 2

The third premise, illustrated in Figure 5, is that industry types (IT, medical devices, finance, etc.) are associated with certain JCAs.

Premise 3: Industry types (IT, medical, etc.) can be associated with JCA's in some meaningful way

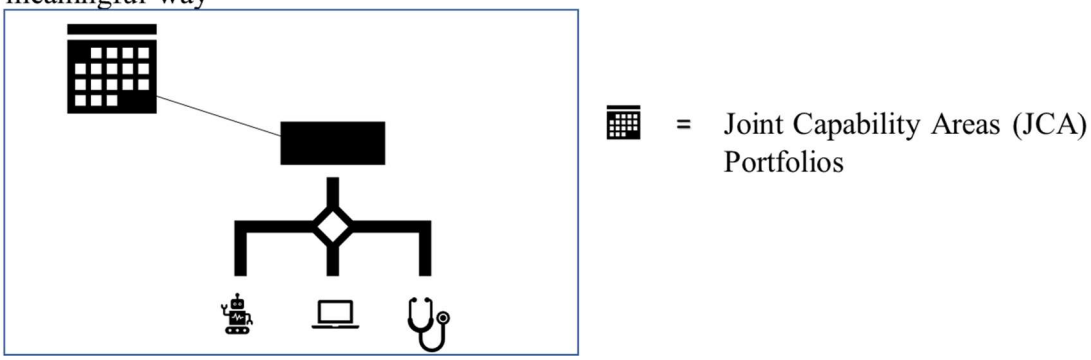

Figure 5: Premise

If premise 1 holds then AFWERX campuses increase regional participation rates. If premise 2 holds, the companies participating reflect the technologies of their region. If premise 3 holds, technologies of a specific type are strongly associated with specific JCAs. The combination of these three premises could explain the differences in capabilities in the portfolio.

Imagine a scenario where all three premises hold. AFWERX builds a new campus in a tech cluster. Because of premise 1, we expect to see higher SBIR participation rates in this area. Because of premise 2, we expect to see that the new participants are involves in similar industries (reflecting the tech cluster they operate out of). Finally, because of premise 3, we expect to be able to observe specific changes in the areas of AFWERX's JCA portfolio which are correlated with that tech cluster or industry. Figure 6 illustrates this scenario, showing how AFWERX's decision to establish a campus might be a predictor for JCA portfolio allocation.

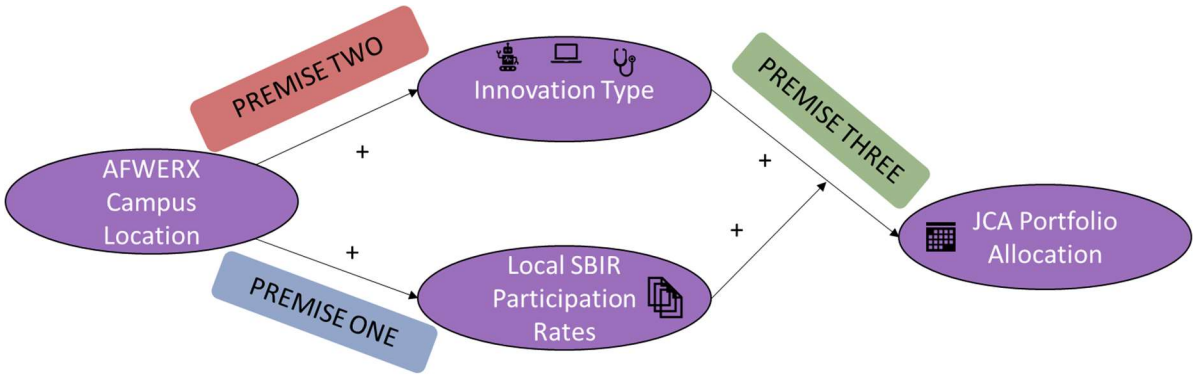

Figure 6: Possible Link of Geological Factors to JCA Portfolio Differences

Premise 1 – AFWERX Campus locations and SBIR participation RatesTest AFWERX and Legacy SBIR for Regional Response Rate Independence

This section shows the results for the following two tests of independence:

Texas

H_0: $\pi_{AOT\_TX} = \pi_{Legacy\_TX}$

H_A: $\pi_{AOT\_TX} \neq \pi_{Legacy\_TX}$

DC

H_0: $\pi_{\mathrm{AOT}\_DC} = \pi_{Legacy\_DC}$

H_A: $\pi_{AOT\_DC} \neq \pi_{Legacy\_DC}$

Results and Conclusions for the Tests of Independence

The results for the tests of independence are shown in Table 7. The Pearson p-values of 0.0114 and 0.0002, for TX and DC respectively, indicate that we reject the null hypotheses of independence, or $H_0: \pi_{AOT} = \pi_{Legacy}$, for both locations.

Table 7: Results for tests of independence between region and organization

Texas

Test	ChiSquare	Prob>ChiSq
Likelihood Ratio	6.306	0.0120*
Pearson	6.397	0.0114*

DC

Test	ChiSquare	Prob>ChiSq
Likelihood Ratio	14.444	0.0001*
Pearson	13.649	0.0002*

The alternate hypotheses, $H_A: \pi_{AOT\_TX} \neq \pi_{Legacy\_TX}$ and $H_A: \pi_{AO\ \_DC} \neq \pi_{Legacy\_DC}$ describe states of dependency between proportions of companies from TX and DC and organization type. Having rejected H_0, we find evidence supporting premise one. That is, we were able to find associations between state SBIR participation rates and the presence of an AFWERX campus. How much does organization type matter? Table 8 helps answer this question with odds ratios.

Table 8: Odds Ratios

Texas

Odds Ratio	Lower 95%	Upper 95%
1.422938	1.081347	1.872435

DC

Odds Ratio	Lower 95%	Upper 95%
5.289888	1.983057	14.11099

The odds ratio results for Texas show an odds ratio of 1.422, which tells us that companies working with AFWERX SBIR programs in 2019 are 1.422 times more likely to have their headquarters in Texas compared with companies working with legacy SBIR programs in the 2016. The odds ratio results for DC show an odds ratio of 5.289, which tells us that companies receiving SBIR funding from AFWERX in 2019 are 5.289 times more likely to have their headquarters in Texas than companies participating in the legacy SBIR program in 2016.

In summary, the results in Table 7, highly significant Pearson p-values, provide statistical evidence for lack of independence. Finally, the odds ratios in Table 8 show just how much higher company participation is for AFWERX in the TX and DC regions. At a high level, these results provide evidence for the presence of geographic effects. These effects may explain differences between AFWERX and AFRL SBIR JCA portfolios. The results also lend credibility to the AFWERX strategy of collocating in tech clusters to tap into the innovative companies working in that cluster.

V. Conclusions

5.1.Chapter Overview

This chapter provides answers to RQ01 - RQ04, limitations on those conclusions, the significance of this research, recommendations for actions, recommendations for future research, along with a summary.

5.2.Conclusions of Research Questions

***Research Question 01* - [RQ01] AFWERX vs Legacy SBIR: Processes**

How does AFWERX's SBIR investment process differ from legacy SBIR investment processes?

AFWERX and legacy SBIR processes differ in many ways, but three stand out above the rest. First, unlike legacy SBIR, AOT SBIR solicitations are open to the entire spectrum of firms and innovations which represents a shift from a pull innovation model to a push; the market is pushing its offerings to the customer. The second major difference is the number and size of awards given by AFWERX; legacy SBIR gives less awards with greater amounts. The third difference we noted was that AFWERX SBIR solicits firms and technologies which are already commercially proven (or at least viable) and which have the potential to be adapted to USAF needs (dual-use); legacy SBIR, however, has the potential to invest in technologies much earlier, perhaps as a first entrant, when technical maturity is low and market synergies non-existent.

***Research Question 02* -** [RQ02] AFWERX vs Legacy SBIR: Commercialization

What commercialization performance differences exist between AFWERX and legacy SBIR programs?

Of the 202 AFWERX companies sampled, 55 received SBIR government funding for a commercialization rate of 37.4%. In contrast, Rask (2018) found a commercialization rate of 7.8% for a random sample of legacy SBIR data (2015-2018).

Research Question 03 - [RQ03] AFWERX vs Legacy SBIR: Military Capability

What differences exist in the military capability portfolios generated by AFWERX and legacy SBIR?

We found highly statistically significant differences (p-value <0.01) in the JCA Portfolios of these two approaches for three categories: Force Integration, Force Application, and Command and Control. AFWERX invests in Force Integration and Command and Control at a higher rate than legacy SBIR. Companies on contract through AOT are 12.8 times more likely to be Force Integration coded and 14.8 times more likely to be Command and Control coded than companies on contract through a legacy SBIR process. Companies on contract through a legacy SBIR process, however, are 19.4 times more likely to be Force Application coded than companies on contract through AOT.

Research Question 04 - [RQ04] AFWERX 'Tech Centers' and SBIR Participation Rates

How do AFWERX innovation hubs located in tech clusters (e.g. AFWERX-Austin and AFWERX D.C.) effect regional SBIR program participation rates?

In states where AFWERX collocated administrative campuses in or around dense tech clusters, AFWERX SBIR participation rates from that region are significantly (and statistically) higher than legacy SBIR participation rates. Companies on contract through the AOT were around 5.3 times more likely to be from DC than companies on contract through legacy SBIR. For Texas, this rate is around 1.4. This finding lends credibility to AFWERX's tech cluster collocation strategy and strengthens (but does not prove) the argument that geographic factors explain JCA Portfolio allocation differences.

5.3.Research Significance

This research looked at over 1000 SBIR contracts to provide insights into the AFWERX's Open Topic SBIR program. The results of these research questions should interest USAF SBIR stakeholders who wish to understand how the AFWERX and legacy SBIR processes compare.

5.4.Recommendations for Action and Future Research

5.4.1. RQ02 Recommendations

Inferences from the results of this research are used as the basis for the recommendations for action provided here. The first recommendation to policy makers and researchers is to explore definitions of commercialization which would increase the comparability of commercialization metrics from different SBIR investment processes. RQ02 highlighted the ways comparing AFWERX and legacy SBIR using commercialization rates can be problematic. The current definition of commercialization does not attempt to distinguish between commercialization resulting from work prior to SBIR program involvement and commercialization resulting from SBIR investments. Additionally, the current definitions of commercialization count non-SBIR matching funds received during Phase II as commercialization. Yet despite the shortfalls of the current definition, commercialization remains and will continue to be an important metric for Congress and other SBIR stakeholders. Therefore, we recommend that USAF SBIR leadership create a new definition of commercialization which accounts for the market-push style of innovation AOT utilizes. The point in redefining commercialization is to make the metric meaningful as a tool for inter-organizational comparison.

The second recommendation we offer to policy makers is to consider the evidence provided in RQ04 whilst making decisions related to the location of personnel and offices involved in innovation functions. Inferring from the results of RQ04, it may be wise to collocate within

innovative ecosystems within the commercial sector on order to tap into the innovation thereabouts. There is a statistical difference between SBIR participation rates in Texas and in DC for AOT and legacy SBIR which may be attributable to the presence of AFWERX front doors in those regions. This research did not prove a causal link between AFWERX tech centers and SBIR response rates, nor did it show whether SBIR participants from a specific region share the industrial characteristics of the areas they operate out of. Future research should explore associations between the presence of administrative offices in tech clusters, SBIR participation rates in those regions, the characteristics of the innovations brought into the SBIR program from a specific region, and a region's industrial characteristics.

5.5.Limitations

Care should be taken when using commercialization metrics for AOT SBIR companies, especially if the intent is to compare those metrics with dissimilar processes (i.e., legacy SBIR). Open Topic researches the feasibility of adapting non-defense commercial solutions to Air Force needs; their ideal technology is *already* commercialized or close to it. Therefore, does commercialization for legacy SBIR firms connote a greater win than it would for an Open Topic firm which may already be receiving cash flows from their commercialized product?

RQ04 Limitations – Regional Effects

The AFWERX data is from 2019 and the AFRL SBIR data is from 2016. These distinct periods of comparison were chosen to avoid problems associate with endogeneity, which arises when there is something related to the response variable and an input variable, and you do not have that something in your model (Sorensen, 2012). AFWERX was created in 2017 and pulls from the same finite pool of SBIR money that AFRL SBIR pulls from. Thus, we chose AFRL SBIR data from 2016 as a point of comparison because it is recent enough to be relevant but

avoids the endogenous problem which would have arisen in later years (when the two organizations began sharing resources).

5.6.Summary

This analysis began by highlighting the inability of the DoD's legacy acquisitions processes and systems to exploit extant technological innovations on relevant timelines. One beneficial but aging cog in the legacy DoD acquisitions wheel is the Air Force SBIR program which has mostly followed the same processes since the 1980s. AFWERX created the Open Topic SBIR program with the help of USAF SBIR stakeholders to refactor and renew legacy USAF SBIR processes. This research focused on comparisons of AFWERX and legacy SBIR investment methods in the areas of processes, commercialization performance, types of military capability invested in, and regional investment rates.

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