THE DETERMINANTS OF MILITARY TECHNOLOGY INNOVATION AND DIFFUSION

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To Frances Wren

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LIST OF SYMBOLS AND ABBREVIATIONS

ACD	Uppsala Armed Conflict Data
AESA	Actively Electronically Scanned Array
AR1	First-Order Autoregressive Process
CINC	Composite Index of National Capability
CSSAD	Committee for The Scientific Study of Air Defense
DII	Derwent Innovation Index
FBM	Fleet Ballistic Missile
FGLS	Feasible Generalized Least Squares
GERD	Gross Domestic Expenditure on Research and Development
GMC	Guided Missiles Committee
GPT	General Purpose Technology
ICBM	Inter-Continental Ballistic Missile
IED	Improvised Explosive Device
IO	International Organizations
IPC	International Patent Classification
IPR	Intellectual Property Rights
MIDs	Militarized Interstate Disputes
MTI	Military Technological Innovation
NASA	National Aeronautics and Space Agency
NIE	National Intelligence Estimate
NIS	National Innovation Systems
NSA	Non-State Actors

NSA	National Security Agency
NSC	National Security Council
NSF	National Science Foundation
NSI	National Systems of Innovation
PATSTAT	European Patent Office Worldwide Patent Statistical Database
PCSE	Panel Corrected Standard Errors
PRIE	Politically Relevant International Environment
R&D	Research and Development
RAF	British Royal Air Force
S&T	Science and Technology
SDI	Strategic Defense Initiative
SIM	Scientific Intelligence Memorandum
SNIE	A Special National Intelligence Estimate
STARS	Surveillance Target Attack Radar System
SUNY	State University of New York
TRP	Technology Reinvestment Program
TSCS	Time-Series-Cross-Section
UAV	Unmanned Air Vehicle
USAF	US Air Force
WIPO	World Intellectual Property Organization
ZIBN	Zero-Inflated Negative Binomial

SUMMARY

A state's capacity to develop and produce advanced military technology contributes to its standing within the global distribution of power. Similarly, the manner in which such technologies, once developed and produced, diffuse throughout the international system affects the relative capabilities of states. These processes – military technology innovation and diffusion – constitute the primary subject of this dissertation. In particular, this dissertation investigates the causes of military technology innovation and military technology diffusion.

In attempt to identify determinants of military technology innovation, I introduce a novel explanatory framework, *threat-capacity theory*, to explain international variation in the capacity to develop and produce novel military technologies. This framework suggests that a state's military technology output will primarily be driven by two factors: the state's threat environment and its innovative infrastructure. In chapter 2, I use this explanatory framework to guide an empirical investigation into state-level variation in military technology patenting incidence. I find that the variables used to approximate *threat-capacity theory* explain much of the international and inter-temporal variation in military technology patenting.

Whereas chapter 2 examines the effect of national security threats over a large number of states and over a long period of time, chapter 3 investigates the manner in which a single salient national security concern can drive innovation. It is well-documented that the 1957 launch of Sputnik I initiated a flurry of US government activity aimed at reducing a perceived shortfall in US scientific, technological, and military capacity vis-à-vis the

Soviet Union. Less well known, however, is that Sputnik's launch immediately preceded a period of rapid organizational and technological innovation within the US intelligence community. Chapter 3 investigates the contribution of the Sputnik scare to this innovation. In particular, the chapter applies Barry Posen's model of innovation to the historical case of post-Sputnik innovation in the US intelligence community. I find the historiographic and documentary evidence to indicate that Posen's theory of innovation has substantial explanatory power in the context of the post-Sputnik United States. In particular, the US intelligence services' improved capacity to collect and analyze information regarding Soviet rocket and missile programs appears to have been initiated by a process of external auditing motivated by an increase in the perceived level of threat posed by the USSR.

The net effect of military technologies on international politics also depends on the extent to which these technologies diffuse. In chapter 4, I use an original dataset of patents assigned to defense servicing organizations to investigate the diffusion of military technologies. Contrary to the predictions of the prevailing scholarship, I find no difference in the rate of diffusion between civilian and military technologies. Neither do military technologies assigned to government agencies diffuse at different rates than those assigned to firms. The overall technological experience of the patent assignee is found to be a positive predictor of the diffusion of military technologies. The effect of the prevailing intellectual property rights regime is ambivalent: when US patents are included in the sample, the effect of patent protection is positive, when the US is excluded, the effect is either non-significant or negative depending on the model specification that is utilized.

Chapter 5 investigates whether the counterintuitive finding that military technologies diffuse at the same rate as civilian ones owes the higher generality of military-funded technologies. In particular, the chapter investigates whether patents assigned to different types of organizations – firms, universities, and government research agencies – vary with regards to their effect on subsequent technological change. I find the organization type to which a patent is assigned to have significant and robust effects on the number of times a patent is cited and its generality. More precisely, I find that university patents are cited more often than corporate patents and that both university and government patents are more general than corporate ones. Additionally, university and governments patents are more likely than corporate patents to be both highly cited and highly general. These results are found to be robust to the use of distinct models, samples, and metrics. This result suggests that the failure to observe higher rates of diffusion in military technologies may be the result of the disproportionately general character of these technologies.

I conclude by considering the contribution of the dissertation to three fields of inquiry: military innovation theory, the theory of the commercialization of knowledge, and social science methodology. The final chapter also proposes, and begins to elaborate, three potential extensions to the dissertation. First, I suggest that *threat-capacity theory* could be strengthened by linking innovation in particular technological areas to particular threats. I provide preliminary evidence that improvised explosive device (IED) countermeasure technologies were developed in response to IED fatalities. Second, I elaborate additional testable hypotheses on military technology diffusion. Finally, I propose a method for the identification of general purpose technologies. I conclude by elaborating a limitation to the dissertation: the failure to consider the interaction between military technology and military doctrine.

CHAPTER 1. INTRODUCTION

1.1 Introduction

"War is unthinkable but not impossible, and therefore we must think about it"

Bernard Brodie (quoted in Kaplan 1991: 34)

During the 2006 Israel–Hezbollah War, Hezbollah forces in Lebanon fired over 4,000 rockets into Israel. The rockets killed 43 civilians, twelve Israeli soldiers, and injured thousands of civilians ("Civilians under Assault" 2007). The attack exposed Israel's vulnerability to rockets and short-range missiles and led Israel's Ministry of Defense to accelerate the development of the Iron Dome missile defense system (Selinger 2013). In 2007, Rafael Advanced Defense Systems was selected to lead Iron Dome development. The system was completed in 2011 and quickly thereafter, demonstrated its military utility. During the 2012 conflict in Gaza, Hamas fired 1,500 rockets into Israel. Interceptor missiles fired from Iron Dome batteries shot down roughly 85% of the incoming projectiles that were predicted to land in inhabited areas. There were only six fatalities associated with the 2012 rocket attacks (Selinger 2013).

In addition to being effective, the Iron Dome missile defense system was highly technologically innovative. The firms that developed the Iron Dome filed patents for many of the system's subcomponents. For example, Rafael filed patents for, *inter alia*, the optical incoming projectile detection system (patent number: US2008191926), the radar network configuration (WO2005003676), the warhead affixed to the interceptors

(WO2008059477), and the means of affixing the interceptor batteries to trucks (US7707922). ELTA, an Israeli defense-servicing firm and subcontractor to Rafael on the project, filed a patent for a method to shield to the Iron Dome's batteries from incoming projectiles (US20090132098) and a vertically stacked array antenna structure for the radar system (WO2010116357). Finally, Rafael and ELTA jointly filed a patent for the highly praised[1] multi-mission radar system used to identify and track incoming projectiles (WO2005003676).

Indeed, the technical features of the system were sufficiently effective to earn praise from missile defense skeptics. Theodore Postol, a prominent critic of the US Patriot missile's anti-ballistic missile capabilities and, more generally, of the US Missile Defense Agency characterized the Iron Dome's performance during the 2012 conflict in Gaza as, "an astonishing achievement – I think it's even fair to use the word miraculous" (Talbot 2012). Postol cites the capability to forgo the launching of interceptors at rockets projected to land in uninhabited areas and its capacity to quickly launch a second interceptor if the first is projected to miss its target as examples of significant new technological features of the system (Talbot 2012).

The story of the Iron Dome's development is not only one of innovation, but also one of military technology diffusion. Whereas the 2006 Israel–Hezbollah War accelerated the project's development, many of the critical technological breakthroughs contained in the Iron Dome were made roughly twenty years earlier under the auspices of the US-led Strategic Defense Initiative (SDI) (Gutfeld 2017). Using funding from SDI research and

[1] For praise for the Iron Dome's radar system see Talbot (2012).

development outlays, ELTA developed the actively electronically scanned array (AESA) radar system. This radar, known as Green Pine, was used in the Arrow theater missile defense system, one of Israel's primary SDI-funded projects. The technological advances contained in the Arrow's radar were critical to ELTA and Rafael's development of the multi-mission radar for the Iron Dome system (Gutfeld 2017). The technical insights contained in the multi-mission radar system, in turn, have been used in at least 32 subsequent technologies including an attack planning system developed by Lockheed Martin, a testbed for small autonomous vehicles developed by Boeing, and a method to jam radars developed by three individual inventors.[2] Thus, even when considering only the technologies comprising the Iron Dome's radar system, a full understanding of the causes and consequences of the Iron Dome as a military technology requires consideration of the contribution of the process of technological diffusion.[3]

The case of the Iron Dome's development contains instances of many of the relationships and processes to be investigated in this dissertation. First, the development of the system appears to have been precipitated by a salient external threat. Chapters 2 and 3 of this dissertation examine the relationship between security threats an innovation. In chapter 2, I consider whether the observed relationship between threats and technological innovation can be generalized. To this end, I introduce a novel theoretical framework, *threat-capacity theory*, to explain international variation in the capacity to

[2] The innovations refer to patents US7769502, US20080033684, and US20140354464 respectively. The number 32 refers to the number of forward patent citations the multi-mission radar system patent has received as of February 3, 2018 (based on Google Patent data).

[3] While this dissertation considers technological diffusion in the sense of the process that describes how an innovation is transmitted between members of a social system over time, the Iron Dome has also diffused in the sense that diffusion is often used in international relations scholarship (i.e., an innovation's transmission between states). The Iron Dome system has already been purchased by Azerbaijan and India. Saudi Arabia (Post 2018) and the United States (Opall-Rome 2016) are contemplating buying the system.

develop and produce new military technologies. I use this explanatory framework to guide an empirical investigation into state-level variation in military technology patenting incidence. I find that the variables used to approximate *threat-capacity theory* explain much of the international and inter-temporal variation in military technology patenting.

Chapter 3 investigates, in detail, the manner in which a single salient national security threat – the USSR's 1957 launch of Sputnik I – can drive innovation. In particular, the chapter applies Barry Posen's model of military innovation to the historical case of post-Sputnik innovation in the US intelligence community. I find the historiographic and documentary evidence to indicate that Posen's theory of innovation has substantial explanatory power in the context of the post-Sputnik United States. In particular, the US intelligence services' improved capacity to collect and analyze information regarding Soviet rocket and missile programs appears to have been initiated by a process of external auditing motivated by an increase in the perceived level of threat posed by the USSR. In sum, chapters 2 and 3 provide evidence suggesting the presence of a *general* relationship between threats and innovation.

Besides pointing towards threats as a potential determinant of innovation, the Iron Dome case illustrates the important contribution of technological diffusion is shaping military technology outcomes. The development of the Iron Dome's radar system depended on the transmission, between individuals, firm, and states, of embedded technical knowledge contained in antecedent technologies. That is, it depended on the process of technological diffusion. Additionally, the knowledge embedded in Iron Dome's radar went on to enter subsequent technological innovations. Chapters 4 and 5 consider technological diffusion is a large sample setting in order to determine the extent to which these observations are generalizable.

In chapter 4, I use an original dataset of patents assigned to defense servicing organizations to investigate the determinants of military technology diffusion. Contrary to the predictions of the prevailing scholarship, I find no difference in the rate of diffusion between civilian and military technologies. Chapter 5 investigates whether the counterintuitive finding that military technologies diffuse at the same rate as civilian ones owes to the higher generality of military-funded technologies. In particular, the chapter investigates whether patents assigned to different types of organizations – firms, universities, and government research agencies – vary with regards to their effect on subsequent technological change. I find that both university and government patents are more general than corporate ones. This result suggests that the failure to observe higher rates of diffusion in military technologies may be the result of the disproportionately general character of these technologies.

I conclude the dissertation by considering the contribution of the dissertation to three fields of inquiry: military innovation theory, the theory of the commercialization of knowledge, and social science methodology. The final chapter also proposes, and begins to elaborate, three potential extensions to the dissertation. First, I suggest that *threat-capacity theory* could be strengthened by linking innovation in particular technological areas to particular threats. I provide preliminary evidence that improvised explosive device (IED) countermeasure technologies were developed in response to IED fatalities. Second, I elaborate additional testable hypotheses on military technology diffusion. Finally, I propose a method for the identification of general-purpose technologies. I conclude the dissertation by elaborating a limitation to the dissertation: the importance of the interaction between military technology and military doctrine.

1.2 Defining Technological Innovation and Diffusion

As the contribution of technological change to fundamental social and economic outcomes has become increasingly evident (Romer 1990; Romer 1994; Zahra and Covin 1994; Bessant et al. 2005), definitions of technological innovation and diffusion have proliferated. While increased scholarly attention on technological change has revealed much regarding the causes and consequences of technological invention, innovation, and diffusion, it has left behind a fractured terminological foundation. Baregheh and colleagues underscore this phenomenon with respect to the term innovation, noting, "Each of these different disciplines proposes definitions for innovation that align with the dominant paradigm of the discipline" (Baregheh et al. 2009: 1324). Significant variation across scholarly disciplines in the usage of these terms suggests the wisdom of defining terminology early in the presentation of research. The sections to follow attempt to describe the primary ways that technological innovation and diffusion have been defined in order to arrive at a set of definitions that are consistent with both academic usage and the measurement strategies used in this dissertation.

In defining technological innovation and diffusion, is helpful to first define technological change. Recognizing that the economic and social impact of new technology depends on the aggregate effect of multiple processes, the term technological change refers to the overall process by which these impacts are produced. Technological change is typically said to be comprised of three sub-processes: invention, innovation, and diffusion (see, for example, Jaffe et al. 2002).[4] This dissertation focuses on the latter two.[5]

1.2.1 Technological Innovation

Approaches to defining technological innovation have tended to proceed by making refinements to the conceptually expansive term "innovation." Joseph Schumpeter was the first to make many of the major conceptual distinctions (Schumpeter 1939; Schumpeter 1942). Subsequent scholars have refined these categories and made additional conceptual distinctions. Some of these distinctions can be justified based on sound conceptual reasoning. Others cannot. For example, distinctions such as that between incremental and radical innovation have, at first blush, intuitive appeal – shouldn't we differentiate between James Watt's steam engine and the transition from the iPhone 4 to the iPhone 4S?[6] However, closer scrutiny reveals that the discrete categorization of radical and incremental relies on an arbitrary demarcation point. Other distinctions, however, hold up to scrutiny. In the sections to follow, I evaluate these distinctions in effort to arrive at a definition of

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[4] While initially conceived (Schumpeter 1942) as occurring in a sequence (i.e., invention leads to innovation leads to diffusion), there has been near scholarly consensus in the rejection of so-called linear models of innovation. This scholarship underscores the bi-directional and non-linear feedback loops between the sub-processes of technological change and thus uses the language of innovation systems.

[5] Invention is omitted from investigation due to long-known problems associated with the identification and measurement of invention. Invention is typically defined as the first occurrence of an idea for a new product (Fagerberg 2006). Uncovering the first instance of an idea, which may occur within the confines of an individual's mind and leave no physical trace, poses obvious problems for scholars attempting to count and categorize instance of invention. In contrast, innovation, as will be shown below, refers to the attempt to bring such ideas into practice and thus frequently leave observable evidence of their occurrence.

[6] Edquist et al. (2001: 14) articulate the distinction between incremental and radical innovations using the terms "minor" and "major" product changes. Other terminology include evolutionary/ revolutionary (Utterback 1996) and original/reformulated (Yoon and Lilien 1985), and discontinuous/continuous (Robertson 1967)

technological innovation that is conceptually tractable and consistent with the measurement strategy used in the chapters to follow. However, before discussing the proposed refinements, I first propose some essential qualities that any definition of technological innovation should possess.

Fundamentally, innovation refers to a desirable departure from the status quo. That is, innovation represents an improvement, not merely a change. Innovation also entails intention; it is not simply an improvement in the relative position of the innovating unit based on a fortuitous exogenous event (e.g., a deterioration in the position of one's competitors or a change in demand conditions).[7]

That an innovation possesses, at least, the trait of being an intentional improvement from the status quo is unobjectionable. Indeed, most scholarly definitions of innovation simply skip past these fundamental aspects of the definition, presumably because they are considered self-evident or entailed in the term. However, further conceptual narrowing is necessary to arrive at a definition of technological innovation consistent with the object of inquiry in this dissertation.

First, the focus here is *technological* innovation. Technology has been defined in various ways by various fields and is often defined broadly. For example, scholars have classified phenomena as varied as language (Changizi 2001), writing (Ong 1986), and horses (McShane and Tarr 2007) as instances of technology. Here technology will be

[7] This is not to discount the role of serendipity on the history in innovation. Alexander Fleming's serendipitous discovery that an unknown mold inhibited the growth of a left out Staphylococcus sample is well known. However, Fleming followed up this fortuitous discovery by growing a pure culture of the unknown mold and systematically testing its efficacy. That is, intentionality was central to the discovery.

defined in a less expansive way as a physical product or process developed from the practical application of technical or scientific knowledge.[8]

Innovations should also be new. Such a novelty requirement is suggested by the term's Latin root (*novus:* new*)*, prevailing scholarly definitions (Schumpeter 1911; Fagerberg 2006), and everyday usage. Schumpeter (1911) establishes the overall terminological president that continues to be used in the academic literature by assigning the term innovation to the first instance and imitation to all subsequent instances.

While Schumpeter's innovation/ imitation distinction advances the definitional task, it raises questions related to measurement. Namely, the condition that that the improvements in question be novel requires determining the first instance a candidate innovation. Measurement of novelty requires accurate information regarding the date on which an innovation occurred. Making such determinations, however, is not always straightforward. Simultaneous or near-simultaneous invention is common (Simonton 1979). In such cases, distinguishing inventor from imitator may be impossible. Further, the condition that an innovation be novel raises questions regarding the appropriate domain on which to apply the novelty criteria. Smith (2006:149) summarizes this problem of domain of applicability succinctly, stating, "Does an innovation have to contain a basic new principle that has never been used in the world before, or does it only need to be new to a firm?" (2006: 149). In the next section, I will argue that the nature of the patenting process

[8] This definition borrows from the Oxford English Dictionary's definition of technology (definition 4c of online edition, accessed January 30, 2018).

provides a practical way of operationalizing Schumpeter's innovation/ imitation distinction.

Another helpful, and commonly made, distinction is that between invention and innovation. The term invention is typically used to refer to the first conception of a new product or process whereas innovation usually refers to the first attempt to bring a product or process into practice (Fagerberg 2006: 4). Thus, the essential difference between invention and innovation is that innovation is the process by which an invention is brought into wider use. Garcia and Calatone (2002) underscore the role of wider usage in differentiating these terms, writing, "A discovery that goes no further than the laboratory remains an invention … Thus, an innovation differs from an invention in that it provides economic value and is diffused to other parties beyond the discoverers (Garcia and Calatone 2002: 112).

The role of time is important in understanding the relationship between invention and innovation. Invention must precede innovation. Becker and Whisler (1967) underscore the role of time in defining the relationship between invention and innovation, stating, "Innovation is a process that follows invention, being separated from invention in time. Invention is the creative act, while innovation is the first or early employment of an idea by one organization or a set of organizations with similar goals" (Becker and Whisler 1967: 463). However, while invention must precede innovation, invention does not necessitate innovation. Schumpeter is largely responsible for underscoring this distinction, noting, in 1939 that, "Innovation is possible without anything we should identify as invention, and invention does not necessarily induce innovation" (Schumpeter biz cycles 1939: 84).

A second commonly made refinement is to distinguish between product and process innovations. Schumpeter defines a product innovation as “the introduction of a new good …with which consumers are not familiar” (Schumpeter 1911: 66). Process innovations, in contrast, are defined as “a new method of production” or “way of handling a commodity” (Schumpeter 1911: 66). In that production methods are used to make products, there is a clear interaction between these two phenomena. Garcia and Calatone, describe this interaction succinctly, writing, “The primary focus of ‘process innovations’ is the efficiency improvement of the production process for ‘product innovations’” (Garcia and Calatone 2002: 112). These definitions haven proved to be remarkable durable with respect to time; Schmookler (1966), Edquist et al. (2001), and Fagerberg (2006) use definitions of product and process innovation that maintain Schumpeter’s early distinction between the introduction of new or improved goods and the introduction of novel production methods.

Various reasons have been offered for maintaining the conceptual distinction between product and process innovation. For example, Edquist et al. (2001), Fagerberg (2006), and Pianta (2006) contend that the economic and social consequences of product innovations are fundamentally different from those of process innovations. For example, Edquist et al. (2001) propose that the conceptual distinction between product and process innovation should be maintained based on the distinct way in which each type of innovation affects employment. Process innovation, it is argued, increases productivity by reducing labor inputs (i.e. workers). In contrast, product innovations, the authors contend, increase productivity by boosting per unit labor productivity. Thus, the authors conclude that the disemployment effects of process innovation are more severe than those of product innovations. The authors summarize their hypothesis as follows; “industries and national economies that specialize in sectors engaged heavily in product innovations generally create more employment than those that specialize in process innovations" (Edquist et al 2001: 121).

I contend that this argument is flawed on a conceptual basis. Both product and process innovations have the potential to produce disemployment effects. Edquist et al. (2001) are correct to point out that process innovations are often the results of substituting capital for labor in the production process. Similarly, they are right to note that such substitutions have immediate effects on employment. However, the same effects are often associated with the introduction of product innovations. Indeed, the mechanism – the substitution of human labor with technology – is the same in both cases. For example, the gradual incorporation of electronics (product innovations) into elevators led to the eventual obsolescence of the elevator operator. Similar product-induced effects eliminated entire job categories such as the switchboard operator, telegraph operator, and lamplighters and can be anticipated to affect commercial vehicle drivers should driverless vehicles be widely adopted. Thus, in the analysis to follow, I do not maintain Schumpeter's distinction between product and process innovation.

Another common distinction is that between incremental and radical innovation. This distinction is based on the size of the improvement associated with the innovation. Incremental innovations represent small changes; radical innovations represent large ones. This distinction stems from the observation of significant heterogeneity in the impact of individual innovations. Certain innovations, such as Cohen and Boyer's 1980 patent procedure for producing molecular chimeras, have demonstrated widespread social, economic, and scientific impact (Azagra-Caro et al. 2017; Feldman and Yoon 2011). Other innovations such as a method of exercising a cat using a hand-held laser pointer (US5443036) can safely be categorized as incremental. Critically, however, incremental innovations need not be trivial. In fact, the cumulative impact of incremental innovations has been found to be large in practice (Lundvall et al. 1992). Indeed, the cumulative impact of incremental technological innovations has been observed in military technology change: this dissertation's primary area of focus (MacKenzie 1989).

In sum, this dissertation defines technological innovation as a novel improvement that is made through the application of technical or scientific knowledge and that is manifest in a physical product or process. Further, technological innovations can be situated on an incremental-radical spectrum depending on the size of the associated improvement from the status quo. Below, I argue that due to certain features of the patenting process, this definition of technological innovation can be validly operationalized using carefully constructed patent-based metrics.

1.2.2 Measurement of Innovation

As much of this dissertation is concerned with innovation as an empirical phenomenon, it is critical that the means by which innovation is measured in subsequent chapters correspond with the conceptual definitions and distinctions made above. The previous section began by asserting that the notion of a technological innovation entailed an intentional technological improvement from the status quo. The nature of the patenting process ensures these preliminary conditions are met.

In essence, a patent is a property right on an innovation that gives its holder the exclusive right to use, transfer, or contract the innovation. Kenneth Arrow provides the prevailing theoretical argument for government intervention via the granting of patents. Arrow (1962) uses a theoretical model to argue that, in the absence of government intervention, societies will underinvest in research and development (R&D). Because, in the absence of patent protection, the outputs of R&D are often non-excludible, investors will be unable to fully appropriate the returns to their R&D investments. This leads to investment below the social optimum. Thus, the primary theoretical rationale – often referred to as the "reward theory" – for patents depends on the patent's role in compensating the inventor for the provision of non-excludable goods such as knowledge. Granting of patents can thus be understood as the means by which the state corrects for market failures that are particular to knowledge-based goods.

To be granted a patent, an applicant must demonstrate in the patent documents that the underlying innovation is non-obvious, novel, and useful. A patent examiner with subject matter expertise in the approximate technological domain of the applicant innovation reviews the patent documents. The condition that a patent be non-obvious, novel, and useful assures that the innovations underlying patents refer to improvements from the status quo.

The use of patents-based measures also ensures that the innovation being measured is limited to technological innovation. Technology is defined here as physical products or processes developed from the practical application of technical or scientific knowledge. In the chapters to follow, only utility patents are used. Utility patents, as opposed to design patents, are only granted to four main categories of phenomenon: methods (process), machines (i.e., physical technologies), articles of manufacture, and composition of matter ("Types of Patents" 2000). Other forms of intellectual property protection cover other forms of innovation. For example, copyrights cover written or musical property and trade secrets cover corporate processes such as strategies, mailing lists, recipes, and operations processes. Thus patents, in that they represent instances of new or improved products or processes and do not include other types of innovation, are able to limit this study's scope to technological innovation.

In the previous section, I described two additional conceptual criteria that are critical to defining technological innovation: novelty and the incremental/ radical distinction. Below, I will argue that the primary means by which this dissertation measures innovation is able to account for these distinctions.

First, the use of patents affords a convenient means of implementing the novelty criterion (i.e., Schumpeter's innovation/ imitation distinction). During the application process, patent examiners review the prior art in order to determine whether the novelty claims made in the patent documents are, in fact, new. Candidate patents for which the underlying innovations are already known to the public are not patentable. Thus, because a patent can only be granted to the first filed instance of an innovation, Schumpeter's imitators are omitted from the data analyzed in this dissertation.[9]

Patent applicants are also required to list as "prior art" all patented innovations that were critical inputs to the applicant innovation. Thus, patents that have frequently been

[9] Since 2013, when the US switched from a standard of first-to-invent to one of first-inventor-to-file system, all patent offices use a first-to-file standard.

deemed critical to future innovation accumulate a large number of citations (these accumulated citations are referred to as “forward citations” in the bibliometric literature). Using these citations to weight individual patents allows patent-based metrics to satisfy another definitional criterion of technological innovation: commensurability with regards to quality (i.e., the incremental/ radical distinction).

Sound measurement requires that the units in question are commensurable. Smith (2006) summarizes this requirement stating, that measurement requires that, “there is at least some level on which entities are qualitatively similar, so that comparisons can be made in quantitative terms” (Smith 2006: 149). If during a given year, countries A and B each produce a single patent yet country A hosted the patent for the development of Cohen and Boyer’s process for producing molecular chimeras and country B hosted the development of the means of exercising a cat using a laser pointer, a measurement strategy that gives an annual innovation score of one to both countries has a commensurability problem. To account for such heterogeneity in patent impact, when using patents as a measure of innovation this dissertation has weighted each patent by its accumulated forward citations.[10] This alternative – citations weighted – method would result in assigning an innovation score of 305 to country A and of 1 to country B for the hypothetical cases described above.

As this example demonstrates, the distinction between incremental and radical innovation is a useful one. However, the utility of the distinction depends on the conceptualization of a continuous incremental-radical spectrum of innovation rather than

[10] Chapter 2 provides a detailed description of how the citations-weighted patent metrics are calculated.

two discrete conditions. Such an approach is taken here. For example, in chapter 5 the range of citations received spans from 0 to 200. Innovations towards the zero end of the range are towards the incremental end of the spectrum, while those approaching 200 are situated toward the radical pole. Using this approach, there is no arbitrary point at which an innovation flips from incremental to radical.

This reasoning also holds with regards to others characteristics of individual innovations. In response to the observation that certain innovations spur subsequent technological progress in a wide range of industries, attempts have been made to specify a subset of General Purpose Technologies (GPTs). I contend, however, that generalness, like the extent to which an innovation is radical, is best conceptualized as the pole of a specific-general spectrum. Thus, in chapter 5, I avoid arbitrary demarcation of innovations as GPTs in favor of a continuous index of generality based on the breadth of technology groups from which a patent's citations are drawn.

In summary, patent-based measures address the novelty problem by means of the patenting process: patent examiners search the prior art to ensure that the novelty claims made by patents are, indeed, new. Second, the patent-based measures used here deal with the incremental/radical commensurability problem by weighting individual patents by their impact on subsequent innovative output.

1.2.3 Defining and Measuring Technological Diffusion

Whereas the definition of technological innovation has been muddled by the term's varied use across a wide range of academic disciplines and its frequent usage in non-scholarly settings, scholarship on technological diffusion is fairly concentrated and there is relatively little non-technical usage of the term. Further, a single prominent scholar's – Everett Rogers– early research on the topic seems to have defined and fixed the definition of diffusion for the field.[11]

Rogers defines diffusion as, "the process in which an innovation is communicated thorough certain channels over time among the members of a social system" (Rogers 2003: 11). This definition is often decomposed into four components: innovation, time, social system, and channels of communication. In the chapters that follow, I conform to Roger's definition of diffusion. Further, the measurement approach of diffusion used in chapters 4 and 5 closely corresponds to Roger's definition.

One distinction between this dissertation's use of the term diffusion and its use in the field of international relations is worth noting. In international relations, diffusion often refers exclusively to the spread of an innovation between nation-states. Using such a definition, an instance of diffusion has occurred at the point when an innovation crosses a national boarder, but not if the innovation had become more widely used within a country. While the definition of diffusion used here includes many instances of international

[11] As of January 29, 2018, Rogers' book Diffusion of Innovations had received 92,381 citations according to Google scholar.

diffusion, because I am concerned with how innovations affect other innovations, limiting the definition in this way would be unnecessarily restrictive.

Diffusion is operationalized in chapters 4 and 5 using forward citation counts.[12] Figure 2 illustrates forward citation process. For a given patent (patents are the units of observation in chapters 4 and 5), diffusion is measured as the number of times the focal patent has been cited by subsequent patents over the five-year period that follows the application date of the focal patent. This operationalization maps closely onto Rogers' four-part definition of diffusion. With regards to innovation, each patent is associated with an underlying innovation that has been deemed novel, non-trivial, and useful. The period of time is five years for each patent. A fixed diffusion time period allows the citation counts to be interpreted as rates of diffusion. That is, the fixed period ensures the commensurability of the count data with respect to time. In the case of patents and patent citations, the social system is the technical community that is working on a technological or scientific area in which the focal patent has proved useful. Finally, while the specific channel of communication is not directly observed in patent citation analysis, it is possible to deduce that a transmission has occurred. Rogers' defines the channel of communication as the means by which information is transmitted between a source and receiver, writing, "a source is an individual or an institution that originates a message. A channel is the means by which a message gets from the source to the receiver" (Rogers 2003: 204). In the case of forward citations, it cannot be known whether the citing patent learned of the cited patent from the cited patent's documentation, a conference, through a journal article, or by some other channel of communication. However, the presence of a forward citation betrays the

[12] Fuller technical descriptions of the specific metrics use are provided in the chapters themselves.

fact that communication between the *source* (the cited patent) and the *receiver* (the citing patent), in fact, occurred.

Patent-based measures are not without their faults. Probably, the most obvious limitation of patent-based metrics is that they omit many technological innovations that are maintained as trade secrets. Patents may also be used strategically (to prevent other firms from using an innovation), and never commercialized by the patent holder. The former problem would lead patents to underestimate the true rate of innovation; the latter would lead to overestimation. Rather than providing an exhaustive account of the potential shortcomings of patent-based metrics, I discuss the construct validity of each metric in the chapters to follow.

CHAPTER 2. THE DETERMINANTS OF MILITARY TECHNOLOGY INNOVATION

2.1 Introduction

On October 4, 1957, from their spaceport *Baikonur,* Soviet engineers and military officers fired a three stage R-7 intercontinental ballistic missile affixed with a 22 inch in diameter aluminum sphere weighing 183 pounds. The rocket generated nearly one million pounds of thrust and launched Sputnik I into orbit. The satellite, highly polished to increase its visibility and assigned a trajectory to pass over population centers, orbited the earth for three months before burning upon entry into the atmosphere (Yanek 2003: 12).

In the US, the launch of Sputnik I was followed by a surge of military research and development (R&D) spending (Brooks 1996; Godin 2003) and a flurry of new science and technology (S&T) policies and agencies.[13] This increased financial and institutional support for defense-related S&T would result in a wave of military technology innovation. Military technologies developed as the result of this increased government support include, inter alia, ballistic missile defense systems (DEFENDER and ESAR), rocket technologies (Juno V booster technology and the Centaur rocket), nuclear test detection (VELA), and a satellite positioning system (Transit).

[13] In 1958, the Advanced Research Projects Agency (ARPA), the National Aeronautics and Space Agency (NASA), and the President's Scientific Advisory Committee were formed. In the same year, the first special assistant to the president for S&T was appointed and the National Defense Education Act was passed in order to increase the number of American science and engineering students.

The popular explanation for this sequence of events is that Sputnik's launch heightened the perceived threat posed to the USA by the USSR, which, in turn, motivated US policymakers to invest heavily in military R&D.[14] That is, an increase in the United States' threat environment led to military technology innovation.[15] Missing from this popular account, however, is the fact the domestic economic conditions in the United States in the late 1950s were such that organizations with a military technology development mandate had the capacity to effectively respond to increased demand on the part of policy makers. In other words, the capacity of the United Sates' innovative infrastructure was sufficiently high to respond to a new threat by developing novel weapons systems. This account suggests the relevance of two factors in driving military technology innovation: a state's threat environment and its innovative infrastructure. In this chapter, I elaborate and test a model of military technology innovation based on these two factors.

The study of the determinants of military technology innovation can be justified in at least two ways. First, military technology superiority (and thus technological innovation, the process by which technological superiority is produced) influences the outcomes of armed conflict and a state's capacity to project power. As early as the fifth century BCE, Thucydides describes how the Boethian's were able to use an early flamethrower during a siege to burn down the Delium fortifications. More recently, the swift US victory in the 1990-1991 Gulf War is commonly attributed to technological superiority, especially the

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[14] Exemplary of the prevailing popular account of Sputnik as impetus for investment is that provided by Neal et al. (2008), who write that "More than any other event in U.S. history, the Sputnik crisis focused the attention of the American people and policymakers on the importance of creating government policies in support of science and of education, with the aim of maintaining U.S. scientific, technological, and military superiority over the rest of the world' (Neal et al. 2008:3).

[15] Recent historical scholarship by Mieczkowski (2013) has revealed that President Eisenhower was not caught off-guard by Sputnik's launch. Nevertheless, the event initiated an immediate flurry of political action to improve the scientific and technological position of the United States vis-à-vis the USSR.

use of precision-guided munitions such as the Air Force's AGM-130 guided missile and the communications support provided by airborne early warning aircraft such as the Navy's E-2 Hawkeye and the Air Force's E-3B Sentry (Hallion 2015). Technology alone is by no means determinative in armed conflict; the history of warfare abounds with examples in which technological superiority was insufficient to ensure victory. Regardless of this caveat, the role of technology in conflict makes the international distribution of the capacity to produce novel military technology an important subject to scholars of international relations.

Second, a large sample empirical investigation of the determinants of national military technology output should shed light onto a long-standing debate regarding the sources of military innovation. Explanations of the sources of military innovation range from those focusing on inter-service competition to those citing intra-service rivalry to theories focusing on civilian-military relations. Much of the theoretical scholarship, however, has treated foreign threats as second order concerns. Indeed, Grissom goes so far as to content that explanations of military innovation based on external threats have been "rejected by the field" (Grissom 2006: 908). This study hopes to determine, in part, whether the subordination of external military threats in the study of military technology innovation is warranted.

The remainder of this chapter is organized as follows. The following section briefly describes the prevailing explanations of military innovation with particular attention paid to each model's treatment of external threats. Section three elaborates my proposed positive theory: the threat-capacity model. The fourth section describes the study's data and methods. Because patent data have not previously been used to measure military innovation, particular attention is paid to demonstrating the construct validity of the metric used here. Fifth, I present results of the time-series-cross-section analysis. The paper concludes by discussing some of the implications of the findings for military innovation and overall innovation research.

2.2 Military Innovation and External Threats

The Sputnik narrative notwithstanding, the majority of international relations' scholarship on the determinants of military innovation focuses on domestic factors. In many of these accounts, the external threat environment is treated as a second-order concern. This section describes the primary models of military technology innovation, placing particular attention on their treatment of external threats.

However, some initial clarification regarding terminology is warranted. This study departs from many previous treatments of military innovation in that it explicitly disaggregates military technology innovation from innovation of military doctrine. The object of study here is military technology innovation. This parsing can be justified in at least two ways.

First, the investigation of military technology in a large sample setting is tractable. The utilization of patent and patent citation data to study international and inter-temporal variation in technological innovation is well established. I am aware of no quantitative data measuring changes in military doctrine. Thus, decoupling technology and doctrine owes, partially, to considerations of measurement.

More importantly, merging technological and doctrinal innovation would introduce simultaneity into the study. It is well documented that novel military technologies can initiate innovation in doctrine (Blasko 2011; Murray and Millett 1998: 1). At the same time, change in military doctrine has been shown to drive military technology innovation (Blasko 2011: 357). The presence of causal links between two dimensions of the object of analysis would prohibit the isolation of the path of action.

2.2.1 Intra-Service Competition

Stephen Peter Rosen's *Winning the Next War* (1991) proposes a model of military innovation based on intra-service competition. Rosen explains innovation as the result of a political process, within a given military service branch, in which senior officers meticulously build support for an idea amongst mid-level officers, whom, in turn, implement the innovation. Because Rosen's model of innovation depends primarily on factors internal to the service branch, the particular features of militaries as organizations are central to his explanation. Rosen explains military innovation during peacetime as a function of "complex political communities" that seek to determine who should rule and how life should proceed for individuals within the community (Rosen 1991:19). Indeed, in Rosen's formulation, the insular nature of military bureaucracies makes them even more political than other forms of bureaucracy. In such a setting, innovation meets resistance not merely from the losers of a resource transfer but due to an associated, ""ideological" struggle that redefines the values that legitimate the activities of the citizens' (Rosen 1991: 20).

The hierarchical organizational structure of militaries and the slow process by which promotion in rank occurs also feature prominently in Rosen's model. A hierarchical distribution of the capacity to make change limits the initiation of innovation to senior officers. However, a high-ranking champion alone will not suffice to implement a nescient innovation. In Rosen's theory, senior officers must institutionalize novel career paths dedicated to performing tasks associated with the new activity. It is not until the occupants of these new posts achieve high rank that the innovation commenced by the original group of senior officers can reach fruition. The combination of the ideological nature of innovation within a military setting, the hierarchical organizational structure, and the slow promotion process necessitates that, according to Rosen's theory, military innovation proceeds slowly and occurs infrequently.

In Rosen's intra-military model of innovation, external threats are treated as secondary to the organizational conditions of the military service branch. In the author's words, "The overall picture of American military research and development in the period from 1930 to 1955 is one of technological innovation largely unaffected by the activities of potential enemies, a rather self-contained process in which actions and actors within the military establishment were the main determinants of innovation" (Rosen 1991: 250).

2.2.2 Inter-Service Competition

Harvey Sapolsky and Owen R. Coté offer a second theory of military innovation based on inter-service competition. This model posits that given scarce defense resources within a state, service branches will compete to maintain and expand their portfolios of capabilities. The result of this competition is innovation.

In *The Polaris System Development* (1972), Harvey Sapolsky argues that the US Navy's successful development of the Polaris fleet ballistic missile (FBM) system owes largely to the fact that the US Air Force (USAF) and Navy were "direct competitors for national missile allocations" (Sapolsky 1972: 38). While Sapolsky is careful to acknowledge the role that the managerial and political skill of the Navy's Special Projects Office and its director Admiral William Raborn played in the successful development of the Polaris, he contends that inter-service competition generated the inertia necessary for the Polaris program to attain the organizational autonomy necessary to succeed within the Navy.

Coté extends Sapolsky's argument by considering its converse. By examining two cases of missile system development, Coté observes that while inter-service *competition* may produce military innovation, *cooperation* between branches of the military can yield technological and doctrinal stagnation. In the case of Polaris, Coté comes to a similar conclusion to Sapolsky citing USAF-Navy competition as vital in spurring innovation in the technological system and the associated nuclear doctrine. When analyzing the case of the Trident II missile system, Coté attributes technological and doctrinal stagnation to the cooperative manner in which the USAF and Navy pursued the technology. Coté describes the innovation-stifling effect of intra-service cooperation, noting, "the Navy suppressed the most innovative aspects of the Trident II system in order to avoid conflict with Air Force systems and continues to embrace existing nuclear doctrine, despite civilian and internal naval support for more innovative technology" (Coté 1995: 7).

Sapolsky and Coté treat external threats as relevant yet second-order concerns. For both scholars, while a heightened international threat environment increases demand for military innovation, security threats alone are insufficient to drive change. In Sapolsky's account of the FBM program, the threat posed by the Soviet Union is acknowledged to have motivated an increase in military spending (Sapolsky 1972: 9). Yet, Sapolsky makes it clear that while "each Soviet advance in missilery served both to reinforce the national consensus to build ballistic missiles and to demonstrate their feasibility…the success of the FBM Program was dependent upon the great skill of its proponents in bureaucratic politics" (Sapolsky 1972: 15).

Coté's treatment of external threats is evident in his research design. Coté examines two cases. One case (Polaris) represents an instance of successful innovation while the other (Trident II) does not. Thus, in explaining variation on the outcome (military innovation), Coté requires variation in his primary explanatory factor. In this case, the variation is found in the presence or absence of inter-service competition. The threat environment is used as a control, facilitating the isolation of causation. Coté describes the similar state of the threat variable for the two cases, writing, "In both cases, the U.S. was experiencing cold war nuclear vulnerability crises, the Missile Gap of the late 1950s and the Window of Vulnerability of the late 1970s, and it was during these periods when the need for innovative nuclear systems and doctrines was at its peak' (Coté 1995: 7).

2.2.3 Threats as Animateur

Whereas theories of military innovation based on intra-service or inter-service competition have tended to subordinate the independent explanatory power of foreign threats, within the models offered by Posen (1984) and Dombrowski and Gholz (2006), threats retain prominence. While their individual accounts vary, both of these explanations describe innovation as a political process in which external threats serve to initiate civilian political energy. It is these explanations that are most directly tested here. They are elaborated briefly below.

In *Sources of Military Doctrine* (1984), Barry Posen posits a civilian-military relations model of innovation in military doctrine. Posen combines the logic of balance of power theory and organizational theory to develop a straightforward logic of doctrinal change. First, Posen contends that the military, if left alone, will tend towards a state of equilibrium or stagnation. However, heightened international security threats will lead a state's civilian leadership to scrutinize the state of its military. The catalyst of civilian intervention, often led by an individual maverick, upsets this stasis and provokes military innovation. Posen summarizes the role of threats in pushing ridged organizations out of equilibrium, stating, "In times of threat, the actions of both statesmen and, to a lesser extent, soldiers will tend to override these dynamics [of organizational stasis]" (Posen 1984: 40).

In *Buying Military Transformation*, Peter Dombrowski and Eugene Gholz explain military technology innovation in the US as the result of a tripartite political interaction between the defense industry, the military, and Congress. The authors begin with the premise that military technology innovation is distinctive from other types of innovation in two ways (Dombrowski and Gholz 2006: 20). First, defense-servicing firms have, effectively, a single customer. Second, the research and development process that is used to produce military technologies is funded by the government in the form of R&D contracts. Both of these features of the defense innovation system – monopsony and government-funded R&D – incentivize firms to make R&D investment decisions in concordance with the stated technology objectives of the military services. That is, neither firms nor markets determine the character of the military innovation; rather the service branches initiate and determine the direction of technological change.

However, in Dombrowski and Gholz's formulation, the military's recognition of a novel technological need does not suffice to drive innovation. For the desired technology to be produced, political support must be generated. Towards this end, the authors contend that the military "needs to assemble a coalition of supporters to convince the political leaders, who control the budget, to buy the transformational technology" (Dombrowski and Gholz 2006: 18). It is at this point that the international threat environment becomes operative. During the process of persuading Congress of the merits of a given project, a heightened threat environment increases Congress' likelihood of acquiescence. According to the authors, "When the threat level is high, Congress tends to defer to the military's professional experience (Dombrowski and Gholz 2006: 22). The authors argue that converse also holds, stating, "when threats are less immediate or visible, Congressional leaders are less likely to defer to the military's professional judgment" (Dombrowski and Gholz 2006: 22).

2.3 *Threat-Capacity Theory* – The Determinants of Military Technology Innovation

Leaders presented with a national security threat will seek means of ensuring their regime's survival in office (Bueno de Mesquita 2005). To this end, a state may, inter alia, change its alliance structure, ramp up domestic production of the current generation of armaments, or purchase weapons from abroad. An additional means of threat mitigation is to develop indigenous military technology innovation capacity. Augmenting a state's military technology innovation capacity may enhance the state's existing technological advantage or undermine the discrepancy regarding relative capacity between the state and its adversary. In either circumstance, an enhanced military technological position is likely to mitigate threats, increase the state's probability of victory in conflict, and force potential future enemies to reconsider the decision to attack the state (Walter 2009).

Leadership volition alone does not suffice to drive innovation in military technology. To do so requires a state to have a domestic innovative infrastructure capable of scientific and technological advancement. This infrastructure is comprised of the resources and institutions used in the process of scientific and technological discovery. The absence of a sufficiently developed innovative infrastructure forestalls the possibility of responding to a threat by accelerating military technological change.

This logic suggests an explanation of international variation in military technology innovation based on two components: a state's threat environment and its innovative infrastructure. Specifically, I argue that a state's military technology capacity will depend on the severity of the threats it faces and the extent of its scientific and technological capacity. In the following section, I define each component of the threat-capacity framework before explaining the logic by which these components interact.

2.3.1 Threat Environment

To define a state's threat environment, I begin with Davis' definition of threats as those situations in which an agent or group has either the capability or intention to impose a negative consequence on the regime (Davis 2000: 10). As either capability or intention increases, so too does the threat posed. The threatening agent or group is defined broadly to include states and internal and external non-state actors. Rather than address all possible negative outcomes, I limit the model's scope to negative national security consequences. These include coups, militarized disputes, asymmetric terrorist attacks, or other type of violent regime change. While threats can have negative consequences in other sectors, such as the economy, these consequences are unlikely to increase a regime's demand for military technology.

A state's threat environment is jointly determined by all of the domestic and foreign threats the state faces. Holding other factors constant, an increase in the threat posed by a given agent or group results in an adverse shock to a state's threat environment.[16] Thus an unfavorable change to a state's threat environment entails an increase in an adversary's ability to impose negative consequences of the state's leadership.

[16] The assumption of ceteris paribus is important here. If threats negatively covary with one another, it is possible that an increase in the threat posed by a given source, will result in a net decrease in a state's threat environment. If two or more threats positively covary, an increase in a given threat may result in an adverse change in the threat environment that is greater than the initial change.

2.3.2 Innovative Infrastructure

I define innovative infrastructure as the resources and institutions within a state that can be utilized to develop novel military technologies.[17] Resources may be human (scientists, engineers, technicians, administrators), physical (labs, equipment), or organizational (universities, government research institutes, firms). Institutions are defined here in the Northian sense of "humanly devised constraints that shape human interaction" (North 1990: 3). They constitute the political and economic setting in which resources are utilized. Holding other factors constant, an improvement in resources or institutions – or in the efficiency with which they coordinate – improves a state's innovative infrastructure.[18]

The phenomenon of interest here is the development of military (not civilian) technologies as a function of a state's innovative infrastructure. While the military/civilian demarcation is not always unambiguous – the literature on dual-use, spin-off, and spin-in technologies focuses on such cases (Alic et al. 1992; Cowan and Foray 1995; Acosta et al. 2017) – the manner in which a typical military technology is developed is distinctive from the civilian technology development process. First, the development of military technologies occurs in a nonmarket context (Peck and Scherer 1962; Mowery 2010, 2012). Military technologies are typically developed for a single consumer, the government. This

[17] While outside the scope of this chapter, the specificity of these resources is likely to affect the speed with which a technological response to a threat may be achieved. While in the long run, resources can be repurposed to military ends, states in which the innovative infrastructure contains components that are already military oriented will be able to more quickly respond to changes in the threat environment.
[18] Again the condition of "all else constant" is important here. Inputs to innovation have been found (Lichtenberg 1984, 1989) to be relatively demand inelastic (it takes many years, for example, to train a scientist, program manager, or acquisition specialist) and thus an increase in the strength of one resource may come at the expense of another if inelastic inputs are merely shuffled between uses.

consumer also typically manages the bidding process, funds development, and sets product specifications.

Second, the military and civilian innovation systems are characterized by distinctive technology development cultures. Alic et al. (1992: 43) identify seven dimensions on which these cultures diverge: product cycle duration, production, priorities, impetus for design, nature of response, R&D and production linkages, and technology sharing. For example, in the civilian system, a mutual and continual feedback process involving autonomous suppliers, producers, and consumers determines product design decisions. In contrast, the impetus for design for military technologies is determined largely unilaterally via the requirements set by the government monopsonist.

I point out the distinctions between the military and civilian innovation systems because these differences affect the conceptualization of innovative infrastructure. These distinctions allow us to subordinate certain factors that promote civilian innovation yet have little bearing on military technology innovation. Specifically, domestic institutions linked to market functioning or inter-firm coordination play a significantly reduced role in the military innovation system. For example, the nonmarket character of the military system depends little on competition-promoting institutions such as product market regulation (e.g., anti-trust regulation) and legal codes that facilitate firm entry and exit (e.g., limited liability, bankruptcy laws, minimal regulatory compliance burdens). Similarly, the coordinating function performed by the government within the military technology development process largely obviates the impact of institutions meant to address coordination failures, such as business organizations that facilitate deliberation. In summary, compared to civilian innovation the institutional requirements for military technology innovation are fairly modest. I thus focus on major cross-cutting economic factors such as knowledge stock, human capital, and economic resources.

2.3.3 The Logic of Interaction

These components – the threat environment and innovative infrastructure – interact to explain a state's likely level of military technology innovation. While neither threats nor innovative infrastructure is profitably conceptualized as taking a binary (yes/no) value, it may be illustrative to consider four extreme permutations. First, if a state with a strong innovative infrastructure is faced with a menacing advisory, that state is likely to pursue the military technology means by which to mitigate this threat. That is, a salient demand for greater military technology combined with sufficient latent science and technology (S&T) capacity to achieve this innovation will likely result in expanded military technology innovation. These causal processes may describe the process by which contemporary Israel, Taiwan, and Cold War US developed sophisticated military technologies. Second, if a state with a weak innovative infrastructure is faced with a threat, that state will be unable to enhance security by indigenously developing military technologies in the short term. Examples here included modern Somalia, Syria, and Nigeria. Third, if a state possesses a strong innovative infrastructure but lacks a salient threat, investment in novel military technology will be largely forgone, and scarce innovative inputs will be diverted to civilian innovation. Exemplary of these dynamics are contemporary Brazil, Finland, Singapore, and Sweden. Finally, states with little domestic innovative capacity and a relative tranquil threat environment will lack both the capacity and the motivation to invest in security by means of military technology. These conditions are illustrated by Ecuador, Peru, Argentina, and Ghana. Figure 1 illustrates the interaction of the threat environment and innovative infrastructure.

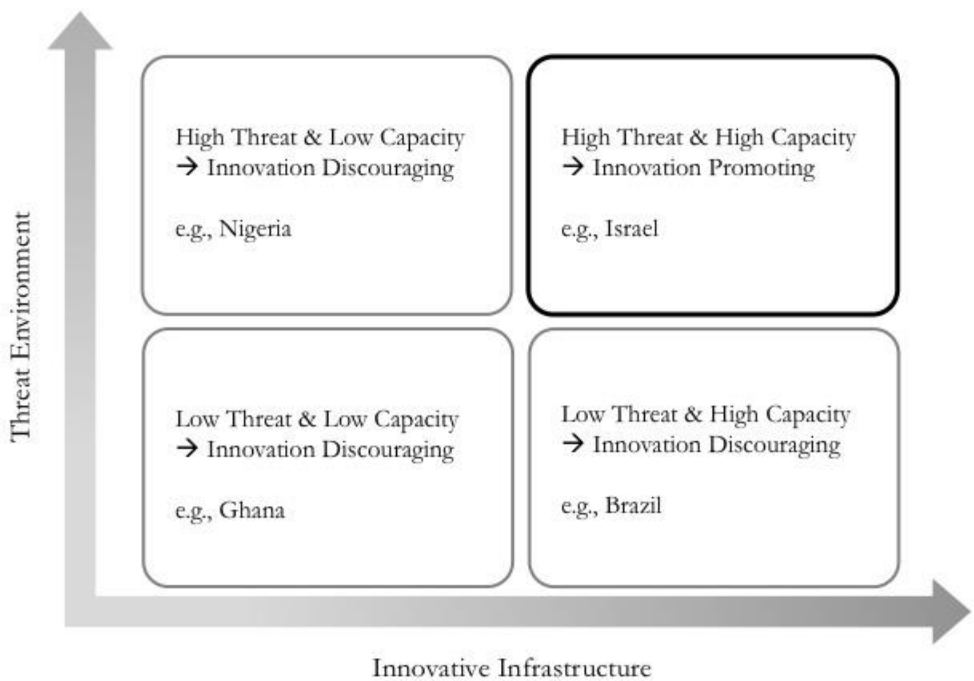

Figure 1 The Threat Capacity Framework

2.4 Data, Measurement, and Modeling Approach

This study focuses on explaining how military technology innovation varies with the external threat environment and the internal innovative infrastructure both across states and within states over time. A time-series-cross-section (TSCS) research design is thus employed. Towards this end, I gather annual data for 52 countries from 1975 to 2007 (inclusive). This universe of cases represents all states that have produced at least one military patent during the period. To measure national military technological innovation, I construct a measure (*MTI*) of annual per capita citations-weighted military patents. I operationalize the proposed model components – security threats and the domestic innovative infrastructure – using proxies from various data sources. Before defining these variables more precisely, the following section justifies the employment of patent and patent citation data in the study of military technology innovation.

2.4.1 Patents as Measures of Military Technology Innovation

While patents have been used to study the diffusion of military technologies (Acosta et al. 2011; Acosta et al. 2013; Schmid 2017), they have not previously been used to measure military technology innovation. Accordingly, a degree of skepticism regarding the extent to which these data adhere to scholarly definitions of military technology is warranted. Rosen provides a two-part definition of military technology innovation that can be used to check congruence between the data used here and the concept these data purport to measure.

Rosen defines military technology innovation as "the process by which new weapons and military systems are created" and asserts that it "is the business of military research and development (R&D) communities" (Rosen 1994: 185). This definition suggests that patent data accurately measures military technology innovation if the patent data identifies new weapons and military systems or system components *and* the innovations are used by the military R&D community.

In regards to the first condition, the patents used here are curated by subject matter experts at Thomson Reuters as *military* technology patents ("Derwent Class Codes" n.d.). That is, the patents do not merely represent novel weapons and weapons systems, but they represent novel *military* weapons and military weapons systems.[19] Also, non-weapons military technologies, such as those employed in defensive, training, and command and control systems, are included. While Table A1 of the Appendix provides a more extensive list of the innovations represented in the sample used here, the five most recent patents from the sample provides an indication of the congruence between the data utilized and the first part of Rosen's definition of military technology.[20] The five most recent patents contained in the sample were granted for a method for the infrared detection, during demining, of buried unexploded objects (patent number: WO2007099054, assignee: individual assignee), a method for processing video images within a shooting simulator (WO2007125247, GDI Simulation), a cavity extender for laser rangefinder or target designator (WO2007103848, Northrop Grumman), a face and iris subject recognition system for use in airports, boarders, and military checkpoints (WO2007103833,

[19] By disaggregating military and civilian technologies, the Derwent Class Code, "W07 - Electrical Military Equipment and Weapons,' that is used here improves on broader classification such as Cooperative Patent Classification System codes F41 (Weapons) and F42 (Ammunition; Blasting) as a measure of military technology.

[20] The appendix provides the names and assignees for the first five patents for the most recent five years of the sample (DII search conducted on January 25, 2017).

Honeywell), and an apparatus and method for guiding a projectile such as a beam riding missile to its target (WO2007099150, Thales).[21]

Second, the major organizations comprising the military R&D community own the patents in the data. Table 1 provides the top twelve patent assignees over the period of analysis. The table shows that the dataset is dominated by large public and private actors that develop and produce novel military technologies (i.e., by members of the military R&D community). The organizations listed in Table 1 correspond to the firms identified by pre-existing military technology innovation scholarship (see, for example, Alic 2007: 74 or Dombrowski and Gholz 2006: 92).

Table 1 Top 12 military patent assignees by country and organization type

Top 12 Military Patent Assignees by Country and Organization Type

Assignee	# of Patents	Country of Origin	Organization Type
US Sec of Navy	1154	US	Government
Raytheon	977	US	Corporate
US Sec of Army	810	US	Government
Boeing	554	US	Corporate
Lockheed Martin	516	US	Corporate
Mitsubishi	501	Japan	Corporate
Messerschmitt-Bölkow-Blohm*	346	Germany	Corporate
Honeywell	342	US	Corporate
Hughes Aircraft	280	US	Corporate
Korean Agency for Defense Development	274	South Korea	Government
KBP Instrument Design Bureau	268	Russia	Government

*Source: Derwent Innovation Index, * Currently part of Airbus Group*

[21] While strictly speaking the most recent five patents in the sample do not constitute a true random sample, the reader is encouraged to consider the patents listed in the appendix for additional evidence as to the character of the data in question. Alternatively, curious readers could search the Derwent Innovation Index using the Derwent Class Code W07 to access the entire database.

In addition to conforming to Rosen's definition of military technology, the use of a patent-based metric allows for the measurement of incremental technological change, which often has a significant impact on overall military capabilities (MacKenzie 1989).[22] Prior research focuses on revolutionary technological systems such as fleet ballistic missiles systems (Sapolsky 1972), tactical nuclear weapons (Evangelista 1988), or the Trident II missile system (Coté 2006). Indeed, Evangelista is explicit in omitting incremental change from consideration, stating, "this term [technological innovation in weaponry] does not refer to the incremental improvements in the characteristic of weapons that arguably constitute the main activity of military research and development' (Evangelista 1988: 51).

Scholars have drawn attention to the problems associated with omitting incremental innovation. For example, MacKenzie argues "the case-study approach typical of most of the empirical work on technology and the arms race is next to useless when it comes to understanding incremental change" (MacKenzie 1989: 172). More recently, Cheung and colleagues have similarly contended that "Unlike the broader analytical literature on innovation, the literature on defense and military innovation tends to equate innovation with major, large-scale change" and laments that such focus "excludes much innovation" (Cheung et al. 2014: 21).[23]

Patent-based metrics capture incremental change by considering "units" of innovation at a finer level of granularity than systems-level technologies. Compared to technology systems, patents are also more temporally proximate to the time of invention.

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[22] MacKenzie gives the example of strategic ballistic missile guidance as an important military technology that emerged through a process of gradual improvement.

[23] Besides MacKenzie and Cheung and colleagues, David Mowery has called for the use of large sample techniques generally (Mowery 2012:1712) and patent data in particular (Mowery 2010:1235) to be employed in the study of military technology innovation.

That is, because patents (in that they are typically subcomponents) are further upstream than end-products, the patent filing date is a closer approximation of the time of invention than is the date of product release. The utility of increasing the granularity of analysis is especially high in the case of weapons systems, which are immensely complex, often involve a systems integrator, and they can take decades to complete (Lichtenberg 1995; Mowery 2010).

This is not to contend that the patent-based measure used here is an exact proxy for military technology innovation. The intellectual property underlying military technologies is often protected via secrecy rather than patenting. These innovations are unobservable to researchers and so not captured here. Further, the data do not capture the effect of spin-in technologies (dual-use technologies that were initially intended for civilian use) on national rates of military technology innovation. However, based on the metric's adherence to Rosen's straightforward definition of military technology innovation and its utility in capturing incremental change, I contend that the measure defined below is a good proxy for the relative military innovative performance across states and within states over time.

2.4.2 Dependent Variable: Military Technology Innovation

To measure national military technological innovation, this study defines *MTI* as annual per capita citations-weighted military patents. Citation-weighted patents are commonly held to be the most credible metric of national innovative output (Taylor 2004). Supplementing patent counts with patent citation data addresses the issue that not all patented technologies are of equal quality or technological import. Within the "prior art" section of their application documents, patent applicants are required to list all patented technologies relevant to the invention underlying the application. "Forward citations" refers to the citations that a patent has received from subsequent patents. Thus, highly cited patents can also be understood to be important to subsequent technological progress.[24] Weighting patents by the number of times they are cited (i.e., by their forward citation count) allows important patents to contribute more to a country's *MTI* measure than patents representing incremental change.

To construct *MTI* requires data on military technology patents, the country of residence of the associated inventors, and the forward citations received by each patent. No single data source contains this information. Accordingly, I use two complementary data sources to build an original dataset of all military technology patenting, inventor residence information, and forward citations for the period 1975-2007.[25]

Towards this end, I first obtain all military technology patents from the Derwent Innovation Index (DII) using Derwent Class Code "W07" (Electrical Military Equipment and Weapons). To attain the country of residence information for each inventor, I use the patent numbers obtained from the DII to query the European Patent Office Worldwide Patent Statistical Database (PATSTAT). I use a separate PATSTAT query to attain the forward citation counts for each patent. I follow convention and use a sliding five-year

[24] This intuition is supported by empirical findings that indicate that forward citation correlate strongly to the opinions of knowledgeable peers about the technological influence of a given patent (Albert et al. 1991) and the patent's market value (Odasso et al., 2015).
[25] Because I use a sliding five-year window to search for forward citations and the 2013 version of the PATSTAT database, the 2008 end point is selected to ensure that each patent has a complete five-year citations window.

window for forward citations, which means that I search five years after each patent date's publication for subsequent patenting for citations.[26]

For a given country-year, *MTI* is calculated as the total fractional count of forward citations received by patents published in that year that are attributable to inventors from that country, divided by the country's population in that year. For example, if a 2005 patent accumulated six forward citations during its five-year window and has three listed inventors, one from Germany and two from Switzerland, Germany is assigned two forward citations (1/3 * 6) for the year for this patent, while Switzerland is assigned four (2/3 * 6) for this patent. This process is continued for every patent published in a given year to arrive at each country-year observation for *MTI*. *MTI*, as are all the data used here, is calculated at the country-year level.

2.4.3 Independent Variables of Interest

I operationalize a state's threat environment using three variables: external security threat, non-state actor threat, and international organization membership. The first two variables are hypothesized to be threat enhancing and thus according to threat-capacity theory should relate positively to military technology innovation. I expect international organization membership to be threat mitigating and should, accordingly, be negatively associated with *MTI*.

[26] Research by Trajtenberg (1990) and Lanjouw and Schankerman (2004) indicates that most forward citations are accumulated during the first five years following a patent's approval.

Innovation infrastructure is also operationalized using three variables: population, GDP per capita, and patent stock. As a state's innovative infrastructure is hypothesized to promote military technology innovation, the anticipated sign of each of these relationships is positive. Table 2 defines and provides the source of each of the variables used in the analysis to follow. Below I elaborate the operationalization of the model components.

Table 2 Variables, definitions, and sources

Variables, definitions, and sources

Variable	Full variable name	Definition	Source
Innovative Output			
MTI	Military technology innovation	Annual per capita citations-weighted military patents (country attribution by inventor)	PATSTAT, Derwent Innovation Index
Threat Environment			
THREAT	External security threat	The sum of the CINC scores of the states within the focal country's PRIE, less the scores from allies and the scores from states whose S score falls below the population average	Data from EUgene software, authors' calculations based on Leeds and Savun's conceptualization (2007)
NSA	Non-state actor threat	Binary variable that takes a value of 1 if a state faced a non-state actor in the focal year	Cunningham et al. (2009)
IO	International organization membership	Total number of international organizations to which a state is a member	Pevehouse et al. (2004)
Innovative Infrastructure			
GDPPC	GDP per capita	Gross domestic product in real 1996 dollars	Gleditsch 6.0
POP	Population	Population	Gleditsch 6.0

Table 2 continued

PATENT STOCK	Stock of international patents	A state's cumulative patens from 1975 until period t-1	World Intellectual Property Organization
Control Variables			
POLITY2	Polity2 score	Polity2 measures a country's political institutions on a 21-point scale from -10 (strongly autocratic) to 10 (strongly democratic)	Polity IV, Marshall and Jaggers (2000)
ARMS IMPORTS	Arms imports	Total annual transfers of conventional weapons from all exporters	SIPRI
MIDs	Militarized Interstate Disputes	Number of MIDs a state is involved in in period t-1.	Palmer et al. (2015)
MIL. EXP.	Military Expenditure	Annual spending on all current and capital expenditures on the armed forces as a percentage of GDP.	World Development Indicators (World Bank)

2.4.3.1 Threat Environment

External security threat: To measure a state's external threat level, I follow the logic proposed by Leeds and Savun (2007). This approach contends that the threat that a given state poses to another depends on the capability of the former and the jointly determined probability of bilateral conflict. I measure capability using the annual composite index of national capability (CINC) scores. CINC scores are a measure of national power calculated as the mean of the focal country's contribution to global totals on six dimensions: population, urban population, steel and iron production, energy consumption, military expenditure, and military personnel (Singer 1972). The likelihood of conflict between two states, in turn, depends on three factors: whether the states are "politically relevant" to one another, whether the states are formally allied, and whether the states have similar foreign policy orientations.

Maoz (1996) introduces the notion of a state's politically relevant international environment (PRIE) to account for the empirical regularity that conflict tends to involve either major powers or contiguous states. Therefore, states are not uniformly concerned regarding the capabilities or foreign policies of other states, but instead focused on their neighbors and states capable of projecting power across space. In defining a given state's threat environment, I thus begin by including only states within that state's PRIE (i.e., regional powers, global powers, and contiguous states).

However, the probability of conflict between states will also depend on their alliance structures and the congruence of their foreign policies. Allied states and states with shared foreign policy orientations are less likely to engage in conflict (Bremer 1992). Consequently, allied states and states with high foreign policy congruence are not considered to be within each other's threat environments. Allies are removed from a state's threat environment calculation based on the presence of a formal military alliance according to the Leeds et al. (2002) ATOP data. In order to remove states with shared foreign policy orientations, the Signorino and Ritter (1999) S score is used. Thus, following Leeds and Savun (2007), I define the external security threat for any given state as the sum of the CINC scores of the states within its PRIE, less the scores from allies and the scores from states whose S score falls below the population average.

Non-state actor threat: Violent non-state actors (NSA) pose at least two types of threat to states. Violent NSAs such as guerrillas, warlords, terrorist groups, criminal gangs, or paramilitaries threaten states by increasing the probability that a regime will be violently deposed. Furthermore, Schneckener (2006, 31-35) points out a second source of threat: the possibility that an NSA will undermine a state's capacity to execute basic functions such as the provision of security, welfare, or the rule of law. As a state's capacity to execute these functions erodes, so does its legitimacy. Legitimacy will be further eroded if an NSA partially supplants the state by executing some portion of the state's responsibilities. As legitimacy erodes, a state's threat environment worsens.

To measure non-state actor threat, I rely on the Non-State Actor dataset (Cunningham et al. 2009). The NSA data builds on the Uppsala Armed Conflict Data (ACD), which identifies instances of state/rebel conflicts responsible for at least 25 casualties in a given year. To create the *NSA* variable, I define a binary variable that takes a value of one for country-years in which a state faced a violent NSA operating within its boundaries and a zero otherwise.

International organization membership: International organizations (IOs) provide opportunities for cooperation among states by increasing inter-state communication, cooperation, and integration (Keohane 1984). According to this view, IO membership should be threat mitigating. Several empirical studies (Russett, Oneal, and Davis 1998; Shannon, Morey, and Boehmke 2010) support the proposed link between IOs and peace.

The international organization variable uses the COW-2 International Governmental Organizations Dataset Version 2.0 (Pevehouse et al. 2004). This data series is comprised of country-year membership observations for the universe of international governmental organizations during the period of coverage. International governmental organizations are characterized as formal (i.e., established through a treaty) organizations and are comprised exclusively of states that exhibit evidence of institutionalization, such as the presence of a secretariat, headquarters, or permanent staff (Pevehouse et al. 2004: 103). In the analysis to follow, for each country-year, the variable *IO* is defined as the number of international organizations (memberships or associate memberships) to which the state is party during the year of interest.

2.4.3.2 Innovative Infrastructure

As mentioned above, I defined innovative infrastructure as the resources and institutions that may be utilized to develop novel military technologies. A state's ability to imitate foreign technology development processes, reverse engineer a foreign military technology, or independently develop a novel defense system will also depend on its cumulative knowledge stock. I follow common practice in the econometric literature on technological innovation (see, for example, Hu and Mathews 2008 and Furman et al. 2002) and operationalize knowledge stock using a state's patent stock. For a given country-year, *PATENT STOCK* is calculated as the cumulative total of patens assigned to residents from a given country from 1975 until the year prior to the observation in question. The extent to which a state is able to allocate resources towards military technology innovation will also depend on the extent of available human and economic resources. I thus include annual measures of population and GDP per capita in the models presented below.

2.4.3.3 Control Variables

King et al. (1994) suggest the addition of control variables that have been consistently found to correlate with the study's dependent variable. However, the absence of large sample studies of military technology innovation prevents such an approach from being used in this case. Instead, I add controls based on factors that represent plausible alterative determinants of the study's dependent variable. Democratic political institutions have been linked to technological innovation (Varsakelis 2006). I thus control for political institutions using Polity 2 scores. Second, it is critical to note that leaders seeking novel military technology have two basic options: to import weapons from abroad or to produce them domestically. I control for the possibility of fulfilling demand for military technology by means of importation by including an arms imports control variable. Finally, it is possible that states actively engaged in armed conflict will develop military technologies at disproportionately high rates. I add a control variable for the number of militarized interstate disputes (MIDs) in which a state is involved as a final control. This variable is lagged one year to reduce the likelihood of endogeneity.

2.4.4 Modelling Approach

The data used here has a time-series-cross-section structure. The panel is comprised of data from 52 states and the 33 years spanning the 1975-2007 period. Beck and Katz (1995: 640) show that, in panels with dimensions such as this, feasible generalized least squares (FGLS) produces standard errors that are excessively optimistic (i.e., they understate the true sample variability). Given a panel characterized by heteroskedastic and autocorrelated errors, I follow Beck and Katz's suggestion and estimate panel corrected standard errors (PCSE) with a first-order autoregressive (AR1) process that is common for all panels. Parameters are calculated using Prais-Winsten estimation.

2.5 Estimation Results

Table III present the results of three different model specifications using PCSE and a common AR1 process. The first specification constitutes the base model of the threat-capacity framework. Model 2 adds controls for democracy, arms imports, and counts of militarized interstate disputes (lagged one year). Model 3 adds a control for per capita military expenditure.

In regards to the effect of the threat environment on national rates of military patenting, the results are clear: a heightened threat environment is positively associated with military technology innovation. Specifically, external security threats and non-state actor threats are each positively associated with rates of military technology patenting. As predicted, the effect of international organization membership on *MTI* is negative.

Similarly, the analysis suggests that a country's innovative infrastructure is positively related to *MTI*. Per capita GDP, population, and patent stock are significant and positive in models 1, 2, and 3. In sum, both of the major threat-capacity model components – a state's threat environment and its innovative infrastructure – are predictive of military technology output.

Table 3 Threat-Capacity and military technology innovation, 1975-2007

Threat-Capacity and military technology innovation, 1975-2007
Dependent variable = citations-weighted military patents

	(1)	(2)	(3)
THREAT	43.98*	92.95*	120.7*
	(2.33)	(2.54)	(2.11)
NSA	18.35**	19.84*	30.94
	(3.24)	(2.53)	(1.93) †
IO	-0.353*	-0.542***	-0.892***
	(-2.43)	(-3.46)	(-3.57)
GDPPC	0.00369***	0.00435***	0.00648***
	(5.63)	(8.10)	(8.84)
POP	1.591***	1.585***	1.882***
	(5.64)	(8.06)	(6.03)
KNOWLEDGE	0.808***	0.700***	0.610***
STOCK	(9.77)	(12.62)	(9.12)
POLITY2		0.464	2.000*
		(1.06)	(2.07)
ARMS IMPORTS		-0.00783	-0.0158
		(-1.06)	(-1.05)
MIDs		7.194	10.05*
		(1.66)	(2.01)
MIL. EXP.			9.084**
			(2.91)
COLD WAR	4.640	10.47	5.762
	(1.17)	(1.79)	(0.63)
POST 9-11	-0.509	-10.06	-14.72
	(-0.13)	(-1.21)	(-1.07)
No. Obs	1287	1128	612
Wald chi squared	139.09***	296.28***	211.71***
Rho	0.825	0.670	0.663

Note: Prais-Winsten estimates, panel corrected standard errors
† p< 0.1, *p < 0.05, **p < 0.01, ***p < 0.001.

2.6 Implications for Future Research

2.6.1 Implications for Military Innovation Research

In a 2006 review article, Grissom claims that the argument that "fear of foreign military capabilities is necessary and sufficient to cause innovation" has "been undercut and ultimately rejected by the field" (Grissom 2006: 908). However, the evidence presented above suggests that this assertion should be reexamined. Further, I believe the presented evidence to be useful in evaluating the prevailing explanations for military innovation.

None of the theories presented above ignore the international security environment entirely. However, within this scholarship, there is significant variation in the degree to which these factors are emphasized. Specifically, models of military innovation based on intra-service competition and inter-service competition treat threats as second-order concerns. The primary causal forces in these models are domestic; indeed, they are internal to the military. In contrast, explanations such as those offered by Posen (1984) and Dombrowski and Gholz (2006) underscore the explanatory power of external threats. My findings support the later set of explanations.

While theories of military innovation that underscore the explanatory role of threats are supported by this study's findings, each of these theories proposes distinct intermediary processes within the causal sequence from threats to innovation. In the Sputnik narrative described in this chapter's Introduction, threats lead to anxiety amongst political elites, which leads to investment, which leads to innovation. In Posen's account, threats lead to anxiety amongst political elites, which leads to civilian auditing of an otherwise change-averse military, which leads to innovation. According to Dombrowski and Gholz, the military constantly appeals to Congress for the resources to fund innovation, but it is disproportionately successful during times of high threat. The research design employed here does not allow for evaluation between these distinctive causal sequences. To do so, it is likely that that carefully designed comparative case studies will be necessary.

Chapter 6 of this dissertation offers the contours of an additional method of testing the Threat-Capacity framework. In particular, Section 6.3.1 suggests that by considering the effect of particular types of threats on particular types of technological innovation, the causal link between threats and innovation could be more precisely defined. In that section, I provide preliminary results suggesting a strong correlation between the onset of improvised explosive device (IEDs) fatalities (a particular threat) and the development of IED countermeasures (a particular type of technology). While the correlational results presented in this chapter suggest that Threat-Capacity theory may have explanatory merit, further investigation into the mechanisms at play would strengthen the case.

2.6.2 Implications for Innovation Research

Currently, there exists a degree of scholarly segregation between the novel multidisciplinary field of innovation studies and the security scholars that study military innovation. In general, these groups of researchers attend different conferences, publish in different journals, and are composed of individuals trained in different academic disciplines. Indeed, the failure of these disciplines to sufficiently intersect has frequently been lamented by their constituent scholars (Mowery 2009: 456; James 2009: 451; Cheung et al. 2014: 19). Recently, scholarship by Taylor (2012, 2016) and Schmid and Taylor

(2017) has attempted to link these oft-orthogonal streams of scholarship by examining the relationship between states' international security context and their *overall* national innovation output. This study's findings have implications for this emerging vein of research.

Taylor's (2012, 2016) creative insecurity theory posits that national innovation rates are determined by two opposing forces: domestic tensions and external threats. The overall effect of these forces on innovation depends on their relative magnitude at any given time. Domestic tensions refer to domestic political opposition to innovation based on the redistributive effects of technological change. The effect of domestic tensions on innovation is thus inhibitory. External threats, on the other hand, are argued to be stimulative of innovation within Taylor's framework. External threats motivate political elites to shore up national security by pursuing innovation-promoting policy that "allows states to better protect their borders and earn foreign exchange for strategic imports via higher value and more competitive exports. Thus, increases in external threats should put pressure on elites—and the interest groups they represent—to support technological change as a solution" (Taylor 2012: 117).

This study offers evidence that one of the two primary variables comprising Taylor's claim may be operative. It also offers a path by which his theory may be evaluated. In terms of supporting evidence, the data analyzed above suggests that security threats indeed appear to be associated with a country's allocation of innovation resources. While tracing this observed relationship to Taylor's proposed mechanism (the allocation, by national political elites, of additional public resources to innovation) requires additional investigation, the findings presented here constitute circumstantial evidence in favor of

Taylor’s thesis. In terms of evaluating creative insecurity theory, the research design utilized here could, without significant modification, be applied to Taylor’s claim that threats drive overall innovative productivity. That is, the operationalization of external threats developed by Leeds and Savun (2007) could be combined with Furman and colleagues’ common innovation infrastructure to constitute the basis of the “right hand side” of a statistical test of Taylor’s theory.

In another example of research linking international security to innovation, a recent article by Schmid and Taylor (2017) finds that, after holding other factors constant, states that have a military alliance with the US have, on average, higher overall national rates of innovation. This effect was found not only for the presence/absence of a formal security alliance but also for continuous metrics of the strength of this security relationship (measured by event counts of joint military exercises and high-level military visits with the US). However, these security linkages were not found to produce a similar effect on military technology innovation. The authors propose that the failure to observe a correlation between alliances and military innovation may be explained by a substitution effect. That is, a military alliance with the US may allow a state to forgo investment in military technology capacity and allocate scarce resources to other priorities.

Combining this result with those presented here yields the intriguing observation that threats drive military innovation yet alliances with the US do not. One interpretation of this observation is that while threats may drive investment in military technology innovation, security alliances with a global power substitute for the development of indigenous of military technology capacity. In other words, alliances allow states to free ride on US military technology. Another possibility is that alliances change states’ perception of threats. That is, alliances may act directly on perceived threats and thus reduce the demand for military technology capacity.

These recent findings linking national security variables and innovation suggest that inter-disciplinary research may prove fruitful. The theoretical origins of innovation studies are closely linked with national defense. In the final chapter of Richard Nelson's (1993) seminal edited volume on national innovation systems (NIS), Nelson observes that "Some of the project members [of the edited volume] were surprised to find that in many of our countries national security concerns had been important in in shaping innovation systems" (1993: 508). Similarly, Christopher Freeman's (1982, 1987) pioneering work in the 1980s on NIS emerged from his study of the US military industrial complex. Reassessing the relevance of these early findings to a globalized defense industry and a distinct international security environment may yield additional insight into the determinants of overall national innovative output.

2.7 Technical Details – Names of five most recent patents of most recent five years of dataset (2003-2007)

The table below contains the names of the five most recent patents for the most recent five years of the period considered here. The table means to provide an indication of the type of technologies contained in the sample used here. That is, it intends to demonstrate that the decision to operationalize military technology innovation using patents is sound.

Table 4 Names of five most recent patents of most recent five years of dataset (2003-2007)

Names of five most recent patents of most recent five years of dataset (2003-2007)
2007
1. Video image processing method for target e.g., helicopter, shooting simulator, involves elaborating image to be viewed from merged image on monitor of simulator, and superposing image to be viewed with digitized image on monitor. 2. Cavity extender for laser resonator of, e.g., laser rangefinders and target designators used during combat operations, includes prism defining a longitudinal axis and including axial faces. 3. Subject recognition system used in e.g., airport access control to secure areas has processing system that is connected to field of view, medium field of view and narrow field of view cameras. 4. Projectile e.g., beam riding missile, guiding method, involves determining position of projectile relative to beams, where position enables to correct projectile trajectory to maintain projectile closer to center of polygon. 5. Infrared detection method of buried unexploded objects in sub-surface layer of soil involves increasing thermal discontinuity between unexploded objects and materials surrounding unexploded objects by local heating of target soil.
2006
1. Light beam aiming dazzler for use by e.g., military personnel, has control electronics provided for processing information from sensor array to discriminate retro-reflected glint and determine its location in visual field. 2. All-terrain vehicle for use with night vision viewing device, has manual infrared light switch whose output opens relay connected between vehicle power and non-infrared vehicle lights when manual infrared light switch is closed. 3. Encryption apparatus and a method for preventing the burglary of a car by using the shock to a driver with high voltage. 4. Infrared ray lamp structure for night vision system of vehicle, capable of illuminating infrared ray into front portion of the vehicle. 5. Self-protection apparatus using a battery of a mobile terminal, allows a user of a mobile terminal to request his/her rescue by pressing a particular key.
2005
1. Atmospheric radioactivity increase monitoring method, involves applying predetermined ratio of proportionality to measured conductivities of air sample to obtain two values and comparing measured values. 2. Combination conductor-antenna apparatus used in projectile, has passage that serves as waveguide to receive conductor to make electrical connection with surface of contact element. 3. Control method of inclination and rotation angles of upper body of munition field units, by controlling angular position of displacement member about longitudinal axis of base over continuous range of angular positions. 4. Preventing or attenuating of passage of unwanted electromagnetic wavelengths into enclosure having transparent area(s) with transparent substrate, involves applying combination of filters to transparent substrate.

Table 4 Table continued

5.	Noise sources detecting and locating method for use in e.g., vehicle, involves digitizing electrical signals, calculating functional, and minimizing functional relative to vectors to determine directions of noise sources.
	2004
1.	Locomotion interface of virtual reality system used in e.g., medical application, has pressure sensing mat that includes several pressure sensing elements which outputs signals indicating pressure applied to top layer of sensing mat.
2.	Sighting device used in combination with shooting instrument, such as bow, has light emitting diode which effects increased brightness of sight point in response to orientation of shooting instrument
3.	Image display device e.g., LCD includes light emitting pixels arranged within optical display, such that pixels of greater density exists in central region of display than in peripheral region.
4.	Battery charging system for e.g., aerospace application, has voltage and current regulators to regulate voltage and current respectively, where system diverts charging current via transistor when voltage exceeds predefined voltage.
5.	Firearm safety device, has two assemblies that are adapted to be secured to firearm on opposite sides of trigger guard, where one assembly has portion with abutment surface that abuts firearm when device is secured to firearm.
	2003
1.	Geophysical survey system has support vehicle with geo-reference system to locate reading from metal detector relative to earth and control unit that regulates power supply to sensor system and geo-reference system.
2.	Impact location determining method for transmitter-bearing object, by transferring data contained in transmitted signal to central processing station which in turn uses data to perform computations to determine the impact location.
3.	Control method for unmanned air vehicle (UAV), by transforming control input into a UAV command in response to the reference angle.
4.	One-chip, low light level color camera used in e.g., nighttime surveillance activities, has image sensor comprising of pixels, in which less than half of pixels of image sensors receive filtered image data.
5.	Video window generation system for graphical user interface, has processor that determines lines of video signal containing image based on density of pixels contained in signal to determine vertical size of window.

CHAPTER 3. INTELLIGENCE INNOVATION: SPUTNIK, THE SOVIET THREAT, AND INNOVATION IN THE US INTELLIGENCE COMMUNITY

3.1 Introduction

The catalytic role of the 1957 launch of Sputnik I in initiating modern US science and technology (S&T) policy is well documented (Dickson 2001; Neal et al. 2008; Yanek 2013). An abbreviated version of this historical narrative might proceed as follows. Prior to 1957, the majority of the intellectual and institutional scaffolding for a national project of scientific and technological advancement were in place. The intellectual rationale is typically sourced to Vannevar Bush's "Science the Endless Frontier," which in the words of Neal and colleagues outlines the, "foundation for modern American science policy" (Neal et al. 2008: 4). Bush's document provides the justification for the funding of basic science based on its role in driving innovation, which is described in the document as being critical to national economic welfare and post-World War II security.[27]

The early institutional framework for modern US S&T policy emerged during the late 1940s and early 1950s. In 1946, the Atomic Energy Commission (later the Department of Energy) and the Office of Naval Research were established. In 1951, the US Army established a research unit; a year later the US Air Force (USAF) did the same. In 1950, the National Science Foundation (NSF) was founded based on Bush's prioritization of

[27] Bush is explicit in linking basic science to innovation, stating, "New products and new processes [] are founded on new principles and new conceptions, which in turn are painstakingly developed by research in the purest realms of science" (Bush 1945).

basic science and his principal that scientists, rather than elected officials, should determine the direction of federally funded scientific research. However, according to this prevailing scholarly account, prior to 1957, the pieces of what would become US S&T policy lay dormant. Large scale funding, political mobilization, and the adoption of Bush's vision would require an exogenous shock: the launching of Sputnik I.

Changes in levels of government funding for R&D supports this claim. In 1935, US gross domestic expenditure on R&D (GERD) was only 0.05%, and the government accounted for just 13% of R&D spending (Brooks 1996). By 1952, GERD has increased to over 1%, and the federal government accounted for 60% of national R&D expenditure (Godin 2003). During the early 1960s (post-Sputnik), GERD reached 2.9% per year, a rate of R&D spending that remains the highest in the country's history. Finally, the NSF's budget was increased dramatically following Sputnik's launch; increasing from $40 million in 1958 to $134 million in 1959.

Besides increasing funding, Sputnik's launch is also argued to have initiated a period of institution and policy genesis. In 1958, the Advanced Research Projects Agency (later DARPA) and the National Aeronautics and Space Agency (NASA) were established. In the same year, the first special assistant to the president for S&T was appointed and the National Defense Education Act was passed. Indeed, DARPA is explicit in citing the contribution of Sputnik to its creation, "DARPA's original mission, established in 1958, was to prevent technological surprise like the launch of Sputnik" (DARPA: Bridging the Gap, 2005: 1).

In short, Sputnik's launch is argued to have initiated a flurry of government activity to address a perceived shortfall in US scientific, technological, and military capacity vis-à-vis the Soviet Union. Less well known however, is that the launch of Sputnik resulted in significant innovation within the US intelligence community. Prior to 1957, the United States' capacity to collect and analyze intelligence on Soviet rocket and missile development was low. Examining the declassified intelligence products produced during this period reveals that the CIA possessed little information regarding the Soviet rocket and missile programs that would, within a four-month span beginning in August 1957, launch an inter-continental ballistic missile (ICBM), launch a 183-pound satellite (Sputnik I), and launch a half-ton satellite (Sputnik II). However, the US agencies charged with the gathering and analysis of Soviet capabilities in these areas responded relatively quickly following Sputnik's launch. Within ten years, the CIA had developed significant novel capacity to gather and analyze imagery, electronic, and communications intelligence and had issued multiple intelligence documents that demonstrate an improvement in the agency's understanding of Soviet capabilities. Given that the "US intelligence infrastructure was in disarray" immediately following World War II (Gordin 2009: 80) and the newly formed CIA (established in 1947) had little capacity to gather intelligence regarding Soviet rocket and missile programs prior to Sputnik's launch, what explains this rapid improvement?

This chapter attempts to answer this question. Specifically, the sections that follow apply Barry Posen's model of innovation in military doctrine to the historical case of post-

Sputnik innovation in US intelligence.[28] Chapter 2 of this dissertation suggested that Posen's model of military innovation was particularly apt – in that it give prominent place to the role of national security threats – in describing military technology innovation. This chapter aims to apply the framework to a different type of innovation: that of the organization and operation of the US intelligence community.

Towards this end, I utilize two sources of evidence: the historical research undertaken by other scholars over the years and primary source documents. To preview the results, the historiographic and documentary record indicate that Posen's theory of doctrinal innovation has substantial explanatory merit in the present empirical context. Namely, the US intelligence services' improved capacity to collect and analyze information regarding Soviet rocket and missile programs appears to have been initiated by a process of external auditing motivated by an increase in the level of threat posed by the USSR. That is, a change in the perceived balance of power caused by Sputnik's launch, spurred political scrutiny of the activities of the US intelligence community, which, in turn, led to innovation. Put plainly, as was found to be true in chapter 2, a deterioration in a state's external threat environment is found here to instigate innovation.

[28] Posen's model seeks to explain innovation in *military* doctrine. Here his model is applied to military and non-military organizations. However, these organizations are similar in that they possess certain traits that should make them (in the absence of external intervention) resistance to change. Specifically, Posen explains that militaries are "parochial, closed, large, endowed with all sorts of resources, and masters of a particularly arcane technology" (Posen 1984: 39). With exception of resources, these traits characterize the pre-Sputnik intelligence community.

3.2 Posen's Model of Doctrinal Innovation

In *Sources of Military Doctrine* (1984), Barry Posen proposes a model of innovation in military doctrine based on civilian-military relations and the balance of power. [29] Posen defines military doctrine as the component of a country's national security strategy that determines *what* and *how* military means are employed towards the realization of the security priorities contained in a country's national security strategy (Posen 1984:13). [30] Innovation is defined as "large change" and is contrasted with incremental change (Posen 1984:47). The relevant portion of Posen's causal logic can be summarized as follows.

Organizations such as militaries or intelligence agencies have, internal, equilibrating characteristics that promote organizational and doctrinal stasis. In the author's words, "organizations place a premium on predictability, stability, and certainty" (Posen 1984: 46). Innovation in this context is rare and is unlikely to originate from within the organization. When innovation does occur, it is initiated by a source that is external to the organization. Posen cites the political leadership as the most common source of such auditing. However, external intervention does not occur randomly. Rather, civilian scrutiny of the military is initiated by a deterioration in a country's international security environment. That is, civilians audit the military during times of increased threat or,

[29] While the term doctrine is typically not used to refer to the activities of the intelligence services, the changes outlined here largely correspond to changes that would in a military context constitute doctrine. Specifically, the employment of novel means (e.g., imagery collection and analysis) to realize a stated end (understanding Soviet missile capacity) represents the kind of innovation that Posen aims to describe.

[30] Posen's definition of military doctrine innovation refers to a departure from the status quo and not necessarily an improvement. At any given time, a state's appropriate course of action might be either stagnation (although Posen advocates a sort of intentional stagnation that is the result of careful deliberation) or innovation depending on the external and internal conditions facing the state. Because whether or not a given change will increase military effectiveness can only be determined following the change (i.e., once the change has been tested in the setting for which it is intended), I also use doctrinal innovation to refer to intentional and significant departures from the status quo.

according to Posen, “anything that increases the perceived threat to state security is a cause of civilian intervention in military matters and hence a possible cause of integration of innovation” (Posen 1984: 79).

Posen’s description of the process by which the British Royal Air Force (RAF) reoriented its doctrine immediately prior to World War II is illustrative of his model of innovation. During this period Britain’s grand strategy was to dissuade aggression through the threat of a long war. Towards this end, Britain sought to maintain a large and protected industrial base and to defend the sea-lanes to her colonies. In sum, the British grand strategy was fundamentally defensive.

However, during the 1920s and 1930s the doctrine of the RAF was *offensive*, centered on executing a first strike. Implicit in RAF doctrine was that an enemy bombing campaign would meet little defensive resistance due to the impracticability of defending against such attacks. Thus, achieving coherence between Brittan’s grand strategy and the doctrine of the RAF required innovation.

In response to “increases in advisory capabilities and evidence of malign intent,” in 1934 civilian officials, along with a handful of champions within the military, began to take positive steps towards bringing RAF doctrine and, the associated technologies, in-line with British grand strategy (Posen 1984: 166). In 1934, the Secretary of State for Air established the Committee for the Scientific Study of Air Defense (CSSAD), to investigate methods for detecting incoming enemy aircraft. Within three months of the CSSAD’s formation, Robert Watson-Watt had demonstrated that radio waves could be used to detect aircraft. A few months later, a well-funded research institute was established. By 1939, the Chain Home radar system had been erected on the Southern and Eastern coasts of Brittan.

The sections that follow apply Posen's model of doctrinal innovation to the case of the post-Sputnik changes in the US intelligence community. If Posen's model has explanatory merit, the following three propositional claims should hold. First, some demonstrable innovation in the doctrine of the intelligence community should be manifest. Second, the actors primarily responsible for change in the intelligence community should be located outside of that community. Third, the intervention of external actors should trace to a change in threat perception. The sections that follow indicate that each of these claims hold in the case of post-Sputnik innovation in US intelligence gathering on Soviet rocket and missile programs.

3.3 Pre-Sputnik Intelligence on Soviet Rocket and Missile Programs

Assessing what the US intelligence community knew of Soviet rocket and missile programs prior to Sputnik's launch requires some historical background regarding the state of these programs during this period of concern. Following World War II, the Soviets took up the task of rocket development in earnest. Immediately following World War II, the USSR established a Scientific-Technical Council for Rocket Development and the Zentralweke rocket development agency both of which sought to replicate German achievements in rocketry, especially the V-2 (Bulkeley 1991:60). Bulkeley explains that during the immediate postwar period, "High priority was given to the establishment of a nationwide complex of rocket research facilities" (Bulkeley 1991:60). In March 1947, Stalin personally took steps to establish a state commission for rocketry. Progress was rapid. By 1947, V-2 test flights had begun. Soviet progress in this scientific and technical realm did not heavily rely on German knowhow.

Awareness regarding these programs within the US intelligence community, however, was relatively low. Both primary sources and the work of other scholars attest to the paucity of reliable intelligence in the pre-Sputnik period. This shortcoming owes largely to a dearth of technical intelligence collecting systems during the 1940s and 1950s. During this period, the US lacked the radio stations and other technological resources required to conduct signals intelligence. For example, the AN/FPS-17 fixed antenna listening station at the Pirinçlik Air Base in Turkey that was eventually used to monitor Soviet missile test flights was not operational until 1955 (Bulkeley 1991:61-62). The National Security Agency (NSA) was not established until 1952 thus leaving the CIA bereft of a reliable means of gathering signals intelligence. The National Photographic Interpretation Center was not established until 1953. Besides the lack of technical means of intelligence gathering, the Soviet rocket and missile programs were not an intelligence priority until the latter part of the 1950s. In 1950, the CIA had only three analysts concentrated on Soviet missile intelligence (Prados 1982: 58).

The United States' lack of intelligence gathering resources during the late 1940s and early 1950s led US intelligence services to miscalculate the USSR's indigenous capacity to develop long-range missiles. A 1955 National Intelligence Estimate (NIE) predicted that the Soviets would launch their first ICBM by 1960 (NIE 11-12-55*)*. In fact, the USSR achieved this feat in 1957, a few months prior to the launch of Sputnik I.

In other cases, errors were made in the opposite direction. In 1949, a Department of Defense technical evaluation group predicted that the Soviets would have long-range guided missiles by 1951-1952 (Gainor 2014). In a similar instance of overestimating Soviet capacity, in a 1955 US Air Force intelligence estimate, analysts incorrectly predicted that the Soviet Long-Range Air Force would surpass US Strategic Command by 1960. In fact, the US held a substantial advantage in this area at the time. Such exaggerated estimates contributed to the myth of a US "bomber gap" and "missile gap" relative to the USSR and were used by supporters such as General Curtis Lemay of a pre-emptive strike against the USSR (Andrew 1998).

The lack of sound intelligence during this period is also evident in the commentary of those tasked with the external evaluation of Soviet programs. For example, the failure of the early intelligence community to gain access to useful information related to Soviet rocketry is evident in the records of the Guided Missiles Committee (GMC). In 1947, the GMC described the status of US intelligence on the Soviet missile program as follows, "it is evident that little or no direct knowledge of work being done at Russian guided missile test ranges can be obtained" (quoted in Gainor, 2014: 43). Gainor summarizes the overall state of US intelligence during this time, stating, "Before embarking on their own ICBM program in 1954, decision makers in the U.S. government had very little solid information on the state of Soviet missile programs" (Gainor 2014: 42). By 1950, Fred Darwin, executive director of the GMC was still concerned about the lack of US intelligence about Soviet missile technology and expressed a concern that the absence of intelligence made comparison of the US program with the Soviet program impossible (Gainor 2014). In 1952, the GMC also expressed concern about a lack of intelligence on Soviet surface-to-surface missiles.

In October 1953, the US Air Force (USAF) assembled a committee to evaluate three nascent missile projects: the Navaho (a rocket ramjet cruise missile), Snark (a cruise missile), and Atlas (an ICBM). The "Teapot Committee" (so named because of its code name) evaluated available intelligence and decided to prioritize the Atlas program. The committee's recommendations are useful in discerning the extent of knowledge in regards to Soviet missile technology in the pre-Sputnik period. As with the GMC, members of Teapot Committee complained about the lack of credible direct evidence related to Soviet space and rocket technology. Specifically, the committee writes, "The available intelligence data are insufficient to make possible a positive estimate of the progress being made by the Soviets in the development of intercontinental ballistic missiles. Evidence exist of an appreciation of this field on the part of the Soviet and of activity in some important phases of guided missiles which could have as an end objective the development by the Soviet of intercontinental missiles. While the evidence does not justify a conclusion that the Russians are ahead of us, it is also felt by the Committee that this possibility cannot be ruled out" (quoted from Rosen 1991: 214).

In the absence of technical means of monitoring Soviet activities, the American intelligence community sought to leverage human sources.[31] Specifically, it was hoped that

[31] On occasion, human intelligence was successfully used to overcome the shortage of technical means of assessing Soviet capabilities. The International Geophysical Year (IGY) was an international scientific research initiative (lasting from July 1, 1957 to December 31, 1958) in which Soviet and American scientists (as well as researchers from other countries) collaborated on a variety of scientific research projects. During this project, Hugh Odishaw, the head of the US National Committee for the IGY, required that all American participants send him any Soviet scientific documents that they may have obtained during the course of the collaboration (Bulkeley 1991:151).

defected German scientists that had worked in the USSR could fill in intelligence gaps. However, the information possessed by these individuals proved not to be current. Gainor explains that such scientists were unable to provide relevant information because they "had been separated from Soviet rocket work since the Soviets had succeeded in launching recovered Germany V-2s in 1947" (Gainor 2014: 43).

Besides a lack of high quality human intelligence sources, Gordin (2009) explains that during the immediate post-war period US intelligence services suffered from a lack of appropriate aircraft. Attempts during the early 1940s to capture images of the USSR by launching high altitude balloons form Europe (with the hope of collecting the descended balloons once they had drifted to Japan) failed. While the US and UK flew planes "crammed with electronic and photographic equipment" along the border of the Soviet Union, President Truman did not authorize a program of shallow flights over Soviet territory until 1950 (Bulkeley 1991:62). It was not until 1953 (seven years after its opening) that Western surveillance planes passed directly over the Kapustin Yar missile development site in Znamensk. Indeed, during the early 1950s the best images of the USSR that the US possessed were those taken during World War II by German reconnaissance planes. Gordin summarizes this early period, stating, "Much of the infrastructure now used to gather intelligence of any kind simply did not exist" (Gordin 2009: 82).

While the evidence provided above supports the contention that prior to Sputnik's 1957 launch, US intelligence on Soviet rocket and missile programs was relatively sparse, one intelligence document issued seven months prior to the launch of Sputnik appears, at first glance, to indicate otherwise. Specifically, a NIE titled "Soviet Capabilities and Probable Program in the Guided Missiles Field" informed the US Government on March

12, 1957 that the Soviets would likely launch a satellite within a year. This document states: “The USSR will probably make a major effort to be the first country to orbit an earth satellite. We believe that the USSR has the capability of orbiting, in 1957, a satellite vehicle which could acquire scientific information and data of limited military value. A satellite vehicle possessing substantial reconnaissance capabilities of military value could probably be orbited in the period 1963-1965.” However, a closer examination of the document raises additional question regarding the quality of the evidence on which this conclusion was made.

The document – recently released under the CIA’s historical review program – is explicit in acknowledging an intelligence shortfall vis-à-vis the Soviet programs: “Although some new intelligence has strengthened our previous estimate that the USSR has an extensive guided missile program, intelligence on specific guided missile systems continues to be deficit” (11-5-57: 1). Later in the document, analysts acknowledge a shortage of evidence regarding the Soviet ICBM program, stating, “We have no direct evidence that the USSR is developing an ICBM, but we believe its development has probably been a goal of the Soviet missile program” (11-5-57: 3) The report then provides an estimate for the timing of the technology’s completion, “We estimate that the USSR could probably have a 5,500 n.m. ICBM ready for operational use in 1960-1961” (11-5-57: 3-4). This estimate of the timing of the completion of the first Soviet ICBM turned out to be incorrect. Indeed, only five months after the NIE was issued, the Soviets launched an ICBM that travelled 3,000 miles. Thus, while the March 12, 1957 NIE accurately predicts Sputnik’s launch, the unclassified public record suggests it had little evidence on which to base this conclusion and made other predictions regarding related Soviet programs that were inaccurate.

In summary, while the March 12, 1957 NIE accurately predicted the launch of Sputnik, the overall quality of US intelligence about the Soviet rocket and missile programs during this period was low. Evidence for this claim comes from erroneous intelligence estimates, the frustrated testimonies of those tasked with evaluating the Soviet programs, and from secondary historical scholarship. However, beginning with Sputnik's 1957 launch, external scrutiny of the status of US intelligence on Soviet programs would increase. Increased scrutiny, in turn, would lead to improved intelligence. The next section traces the process of auditing that followed the satellite's launch.

3.4 The Launch of Sputnik I, the Heightened Soviet Threat, and Increased Scrutiny

At 11:56pm on October 4, 1957, from the newly completed Baikonur rocket testing facility in Soviet *Kazakhstan*, the Soviet Union launched a three-stage R-7 rocket. The rocket, which generated one million pounds of thrust, delivered its payload, a 22-inch 183-pound aluminum sphere into low earth orbit. Tellingly, the US was not monitoring for satellites when Sputnik I was launched (Dickson 2001: 11). Indeed, the satellite passed over the US twice before, the Moscow bureau of *New York Times* broke the news in the US (Bulkeley 1991: 3).

Sputnik's launch was followed in quick succession by the launch of the 1,120-pound Sputnik II on November 3, 1957. Indeed, due to its weight, Sputnik II may have had a greater effect on US leaders' perception of the USSR as a potential threat to reaching the continental US with an ICBM (United States 1958: 8). This section will demonstrate that these events had two effects. First, the launch of these satellites increased the perceived military threat posed by the USSR amongst US political leaders. Second, the demonstration of Soviet rocketry capacity elicited an immediate political reaction. Specifically, the launch of Sputnik I and II resulted in high-level political scrutiny into the manner in which the intelligence services gathered and analyzed information pertaining to the Soviet rocket and missile programs.

The threat posed by the Sputniks' launch had little to do with the satellites and much to do with the rockets that sent them into orbit. Launching a heavy object into orbit required sophisticated, or at least powerful, rocketry technology, which suggested that the newly nuclear USSR was making progress at constructing rockets capable of reaching the US. In a 1958 article in *International Affairs*, Denis Healey, a member of the British parliament who would later become Defense Secretary of the UK, describes the security ramifications of Sputnik is stark terms, stating, "From the military point of view, the Sputnik means that Russia has the capacity to produce a missile which is capable of carrying a thermonuclear warhead a distance of some five thousand miles in something like twenty minutes, and of guiding that missile with sufficient accuracy to destroy the Capitol building in Washington" (Healey 1958: 145).

The military consequences of Soviet rocketry capacity were also evident to members of the US Congress. According to Galloway, "the news struck Capitol Hill like a thunderbolt because thrusting the 184-pound satellite into outer space was evidence of the capability of launching intercontinental ballistic missiles, and therefore instantly perceived as a crisis for U.S. national defense” (Galloway 2000: 209). Then-Senator Lyndon Johnson expressed his concern in particularly colorful terms, fearing that that the Soviets would, “Soon [] be dropping bombs on us from space like kids dropping rocks onto cars from freeway overpasses” (quoted in Kuhn 2007: 12).

The threat to national security was also perceived in the executive office. Eleven days following the launch of Sputnik I, Vice-President Nixon delivered a speech to the International Industrial Development Conference in San Francisco in which he described Sputnik’s launch as a “a grim and timely reminder of a truth that we must never overlook -- that the Soviet Union had developed a scientific and industrial capacity of great magnitude” (Nixon 1957: 2). A few months later this sentiment was echoed by President Eisenhower who on January 20, 1958 characterized the USSR space dominance as a direct military threat (Peoples 2008: 60).

Besides increasing the perceived threat posed by the USSR, the launch of the Sputnik satellites was immediately followed by increased high-level scrutiny into the activities of the intelligence community. Dickson characterizes the political reaction to Sputnik as “instantaneous” (Dickson 2001: 11). On October 11, 1957 the Senate Armed Services Committee requested that the Department of Defense provide them with a report “on the Soviet satellite and missile program furnishing all information available” (quoted Prados 1982: 64). Additional scrutiny came in the form of a December 1957 request for the CIA to compile a Special National Intelligence Estimate (SNIE).

The activities of the National Security Council (NSC) within the two years following Sputnik were dominated by the topic of Soviet rocketry. In January 1958, Director of the CIA Allen Dulles personally gave the NSC a briefing on the Soviet programs. The topic of the USSR's missile programs was raised at least nine times at NSC meetings in 1958 (Prados 1982: 82). In the following year, there were ten NSC meetings dedicated to the topic of the Soviet programs and four "detailed exchanges" on this topic between the CIA and the President's Science Advisory Committee (Prados 1982: 85).

Congressional oversight of the CIA's post-Sputnik activities extended beyond hearings. Senator Symington, President Truman's Secretary of the Air Force, personally visited with the Board of National Estimates at the CIA's headquarters in order to learn the process by which NIEs were produced. This was the first time any Senator had met with the Board of National Estimates on official business (Prados 1982: 83).

Scrutiny of intelligence estimates extended to the office of the President. Following Sputnik, President Eisenhower became increasingly interested in the process by which intelligence estimates were produced. In fact, in March 1958, Eisenhower described one CIA estimate as comparable to the work of high school students (Prados 1982: 78).

Post-Sputnik scrutiny extended beyond the work of the intelligence community. Of particular attention was the state of the US missile and space programs. Less than two months following the launch of Sputnik I, the Senate Armed Services Committee convened a hearing to assess the state of US aerospace capacity relative to the USSR. Specifically, on November 25, 1957, then-Senator Lyndon B. Johnson (Chairman of the Preparedness Investigating Subcommittee) began the "Inquiry into Satellite and Missile Programs." These meetings continued into January 1958 and the transcription of the various testimonies filled 2,476 pages. Scrutiny into the status of the US programs also came from the US House of Representatives. On March 5, 1958 the Committee on Astronautics and Space Exploration was formed to evaluate the future of the US space program.

3.5 The Post-Sputnik Improvement in US Intelligence

In the period following the 1957 launch of Sputnik, the US intelligence services made significant improvements in their capacity to monitor and analyze the activities of the USSR. Specifically, during the immediate post-Sputnik period three novel intelligence resources came online: new NSA Soviet monitoring facilities, the advent of a US spy satellite program, and an improved institutional capacity to interpret imagery intelligence. These added resources were supplemented by an increased propensity for the individuals involved in the task of Soviet intelligence gathering to communicate across institutions.

One major reason for the post-Sputnik intelligence improvement is the actions taken by the NSA to gather additional electronic and communications intelligence on the USSR. During the late 1950s, the NSA established facilities in the UK, West Germany, Turkey, Japan, Italy, Greece, and Ethiopia. In 1958, a radar facility to monitor Soviet rocket launches was established on the Aleutian Islands (Prados 1982: 103). In 1959 a listening post with a similar aim was established in Peshawar, Pakistan. In 1960, the NSA established an additional facility in Iran.

Additional information regarding Soviet activities came from the United States' own reconnaissance satellite program. After various failed attempts to put a reconnaissance satellite into orbit, the Discoverer 13 and 14 satellites were successfully launched in August

1960. Their film capsules – the first manmade objects ever retrieved from space – were recovered later that month. The timing of the program's onset was fortuitous as the US stopped flying U-2s over the USSR after a crashed plane, its camera, and pilot were recovered in Soviet territory in 1960. In fact, the satellite program produced higher resolution images than the U-2 flights and, at that point, there was no threat that a satellite would face Soviet counter-measures. The satellite program cost an estimated $1.3 billion from 1957-1960.

The post-Sputnik intelligence community also took actions to increase their capacity to analyze images. In January 1961, President Eisenhower established the National Photographic Intelligence Center within the CIA to provide expertise in the interpretation of incoming satellite images. Prados contends that these efforts to increase the capacity to interpret photographic images were largely successful, stating, "[b]y 1960 the essential of a massive intelligence-collection and-interpretation capability were in place" (Prados 1982: 110).

Finally, the post-Sputnik improvement owes, in part, to an increased willingness by individuals involved in the task of monitoring Soviet missile development to work across institutional boundaries. For example, during this period the chief of Soviet intelligence within the CIA's Deputy Director for Plans began to attend meetings of the Board of National Intelligence Estimates (Prados 1982). White House staff members with Soviet intelligence responsibilities attended these meetings as well.

Evidence of the post-Sputnik intelligence improvement is found in the increased sophistication of the CIA intelligence estimates produced during this period. For example, a declassified series titled the "Soviet Space Program," demonstrates the efficacy of the novel intelligence resources described above. Beginning in 1962, reports for this series were issued every two to three years until 1985. Each release of the series demonstrates an enhanced technical understanding of the Soviet programs.

Improved intelligence following Sputnik, however, was not immediate. In a December 1957 Scientific Intelligence Memorandum (SIM) the CIA estimates were imprecise. The SIM concludes that Sputnik III would deliver one of four payloads: a 160-300 lb. scientific earth satellite, a large satellite containing a live mammal, a 1000-5000 lb. reconnaissance satellite, or a lunar impacting payload (Future Soviet Earth Satellite Capabilities 1957: 1-3). While the satellite weighed 3000 pounds, the breadth of options provided by the SIM suggests that the immediate post-Sputnik CIA still lacked significant intelligence capacity. Similarly, the first post-Sputnik Soviet Space Program NIE, issued in 1962, still uses a strongly worded caveat regarding the conclusions drawn, "Our evidence as to the future course of the Soviet space program is very limited. Our estimates are therefore based largely on extrapolation from past Soviet space activities and on judgments as to likely advances in Soviet technology" (11-1-62: 1). Indeed, the content of this document primarily comes from publically available resources such as the official statements of the USSR.

By 1965 such caveats had been completely removed from the NIEs, and the technical sophistication of the estimates had been significantly improved. The twelve technical appendices in a 1965 NIE illustrate such an improvement (NIE 11-1-65). These appendices cover, in detail, topics such as Soviet scientific and technical capabilities for space flight, new propulsion and guidance systems, and tracking and communications systems.

In a 1967 Special Report titled “The Soviet Space Program Ten Years After Sputnik I,” which was declassified in November 2006, the CIA demonstrates a post-Sputnik improvement in understanding of Soviet programs. In particular, the report notes that the Soviets had launched over 250 satellites in the ensuing ten years and correctly observes that the Soviet’s had been able to exploit eight of the nine ideal Mars and Venus launch windows since 1960. The accuracy of these detailed observations demonstrates the extent to which the CIA expanded the its intelligence gathering capabilities in the ten years following Sputnik.

Besides describing the scale of the Soviet space program, the Special Report shows a sophisticated understanding of the technical difficulty associated with certain Soviet accomplishments. Specifically, the report describes the Soviet’s ability to capture images of the hidden side of the moon as “a brilliant achievement” (The Soviet Space Program 1967: 2). The report also describes the Soviet’s frustrations and failures. In particular, the report observes that during this period nine Soviet attempts at interplanetary exploration failed to exit the earth’s orbit and describes the Soviet frustration with “the fact that every probe put into an interplanetary trajectory suffered a communications failure prior to reaching its objective (The Soviet Space Program 1967: 2).

The 1967 report also proved prescient. In particular, the report predicted that the Soviets would attempt to launch probes to Venus during the January 1969 launch window. In fact, during this window the Soviets would deploy the Venera 5 (January 5, 1969) and

Venera 6 (January 10, 1969) atmospheric probes which transmitted data on Venus' atmosphere (Harvey and Zakutnyaya 2011). The report also predicts the USSR's attempt at a manned lunar landing within the next five years (1968-1973). Indeed, the period in question witnessed a failed Soviet attempt to send manned spacecraft to the lunar surface (Hardigree 2010).

3.6 Conclusions

In their book on US science and technology (S&T) policy, *Beyond Sputnik: U.S. Science Policy in the Twenty-First Century*, Neal et al. (2008) articulate the prevailing account of Sputnik as impetus for change, stating, "More than any other event in U.S. history, the Sputnik crisis focused the attention of the American people and policymakers on the importance of creating government policies in support of science and of education, with the aim of maintaining U.S. scientific, technological, and military superiority over the rest of the world" (Neal et al. 2008: 3). The preceding analysis has attempted to demonstrate that the result of this focused political attention extends beyond the domain of S&T policy to the intelligence community. In particular, this chapter has attempted to determine whether Barry Posen's model of doctrinal innovation holds explanatory merit in the empirical case of the post-Sputnik improvements in the capacity of the US intelligence services. Towards this end, it is argued that Sputnik increased the perceived threat posed by the USSR. This increased threat led US policy makers to direct their attention to the United States' capacity to collect and analyze intelligence on Soviet missile and rocket programs. This external auditing resulted in improved intelligence estimates on the topic of Soviet rocket and missile capacity. In other words, Posen's model of doctrinal change demonstrates significant explanatory merit in the case of post-Sputnik innovations in the US intelligence apparatus. Combining this result with those of chapter 2 suggests that Posen's framework has significant explanatory merit outside of his original cases of interwar France, Britain, and Germany.

However, the importance of the improvement in US intelligence about the activities of the USSR extends beyond the theoretical. Gaining a more accurate picture of Soviet capabilities may have played a critical role in ensuring the Cold War remained cold. As described above, in the absence of sound empirical evidence, distorted understandings of the capabilities of a given adversary may prevail. Such distorted estimates – in either direction – can increase the possibility of conflict (Renshon 2009). For example, the myth of the Soviet "missile gap" from 1957-1961 is argued to have motivated both the Eisenhower and Kennedy administrations to propose larger defense expenditures than they would have in the absence of exaggerated perceptions of Soviet capabilities (Wenger 1997). Andrew concurs with the contention that improved intelligence may have decreased Cold War tension. In particular, Andrew suggests that if the immediate post-war dearth of intelligence had continued, the Cold War may have reached a heightened state, asserting, "If all presidents had possessed as little intelligence on the Soviet Union as Truman, there would have been many more missile-gap controversies and much greater tension between the superpowers" (Andrew 1998: 328).

CHAPTER 4. THE DIFFUSION OF MILITARY TECHNOLOGY

4.1 Introduction

In many countries, the portion of total government research and development (R&D) expenditure that is occupied by military-directed R&D is substantial. In 2015, the United States spent US$73.5 billion on defense R&D ("Historical Trends" 2016). This represented 52.4% of 2015 federal R&D outlays, 12.1% of total defense spending, and nearly 20% of all 2014 US R&D spending ("National Science Board" 2014). While the share of government R&D occupied by defense R&D is higher in the US than in most other countries, public spending on defense R&D is substantial in many OECD countries as well as in Russia and China (Brzoska 2006). While the primary purpose of defense-directed R&D is to ensure future military preparedness, such large investments have the potential to produce large second-order effects on overall innovative output. The magnitude of these second-order effects will depend largely on the extent to which the knowledge generated by defense funding is used in subsequent civilian-oriented processes, products, and services. That is, the impact of defense spending on overall innovation will depend on the rate at which defense-funded knowledge diffuses into subsequent innovations.

This chapter investigates the diffusion of defense-funded knowledge by considering the diffusion of the objects in which much of this knowledge is embedded: military technologies. Using an original dataset of patents filed by defense-servicing organizations, I use negative binomial and zero-inflated negative binomial regression models to test four hypotheses derived from the existing military technology diffusion literature. The study's most striking finding is that after controlling for other factors documented to affect diffusion, there is no statistically significant difference in the rates at which military and civilian technologies diffuse. This finding contradicts the prevailing scholarly view that idiosyncratic features of the modern defense sector serve to limit the diffusion of technologies developed therein. Neither does the study find evidence in support of the claim that military technologies assigned to government agencies diffuse less readily than those assigned to firms. On the other hand, the evidence considered here does support the claim that an organization's overall technological experience relates positively to the rate at which the military technologies it develops diffuse. Finally, the results in regards to the effect of intellectual property rights (IPR) regime are ambivalent, yet intriguing. Specifically, when patents assigned to US-based organization are included in the analysis, the effect of IPR protection is significant and positive. However, omitting these patents changes the sign of the effect.

In addition to advancing understanding regarding the manner in which defense R&D spending affects overall innovation, the study of the diffusion of military technology can be justified in at least two ways. First, despite the significant contribution of defense R&D spending to industry, university, and government research and innovation, the mechanisms by which military spending affects national systems of innovation (NSI) are under-studied.[32] There are several reasons for the persistence of this research gap.[33] First, information on defense-related outputs, especially at the level of systems development, is often kept secret. Second, the first wave of NSI literature focused on small Scandinavian or central European countries characterized by low defense spending (Mowery 2009: 456).

[32] The foundational NSI references are the volumes edited by Lundvall (1992) and Nelson (1993).

[33] One notable exception to this pattern is Mowery (2009), which locates post-Cold War US defense spending within a national systems of innovation framework.

While NSI has more recently been applied to a greater mix of countries, the role of the defense sector is rarely carefully specified (Mowery 2009). Finally, there is a degree of scholarly segregation between innovation-focused and defense technology-focused researchers (James 2009). This has led to a well-developed NSI literature and a robust body of scholarship on national defense R&D processes yet little research focusing on how defense funding and technologies affect innovation systems.

Illustrative of this research gap is the absence of statistical evidence for many of the claims made in the diffusion of military technology literature. As will be described in Section 2, there is near scholarly consensus that, relative to contemporary commercial technologies and military technologies of the past, modern military technologies have little effect on the larger innovation landscape. That is, there is widespread agreement that the relative diffusibility of military technologies is low. This claim, however, lacks large sample empirical support. With few exceptions, subsequent empirical research into the character of the diffusion of military technology has used a case study approach (see for example, Alic et al. 1992; Kulve and Smit 2003; Goldman and Eliason 2003; Avadikyan et al. 2005; Bellais and Guichard 2006; Horowitz 2010).[34] Indeed, Mowery (2012, 1712) laments the lack of "compelling quantitative evidence" in regards to claims regarding how defense technologies interact with civilian technologies. In another article, Mowery (Mowery 2010: 1235, 1253) calls for the use of patent data to fill this empirical void. This chapter takes up this challenge and attempts to interrogate empirically, through the use of

[34] The only exceptions to which I am aware are studies by Acosta et al. (2011; 2013). While these investigations use statistical techniques, they consider a distinct aspect of diffusion to that considered here. In particular, Acosta et al. do not investigate the relative diffusibility of civilian and military innovations; instead they consider a sample comprised exclusively of military innovations.

patent and patent citation data, some of the most common claims regarding the diffusion of military technologies. Whereas chapter 2 used patent and patent citation data to investigate the determinants of military technology innovation, this chapter applies a distinct empirical strategy to the same type of data to investigate how these technologies diffuse over time and space.

Second, the ambivalence of the extensive econometric literature on whether defense spending increases economic growth points to the need to understand the underlying causal mechanisms. A multitude of empirical studies using various modeling techniques on data from a wide range of countries and time periods demonstrate that defense investment is positively associated with economic growth rates (Atesoglu 2002; Atesoglu and Mueller 1990; Brumm 1997; Halicioğlu 2006; Mueller and Atesoglu 1993).[35] Unfortunately, an equally broad variety of studies comes to the opposite conclusion (Dunne and Nikolaidou 2012; Faini at al. 1984; Mintz and Stevenson 1995; Mylonidis 2008; Shahbaz at al. 2013; Ward and Davis 1992). While the present contribution does not directly examine the impact of military investment on economic growth, it does begin to illuminate a critical underlying mechanism: the process by which military technologies interact with subsequent innovation.

The remainder of this chapter proceeds as follows. Section 2 examines the existing scholarship on the diffusion of military technology and extracts four testable claims. Section 3 outlines the data and methods used to test these hypotheses. Section 4 presents

[35] For a summary of the debate concerning the relationship between defense spending and growth that focuses on the role of model selection see Dunne et al. (2005). For a non-technical summary of the debate see Ram (2005). Alptekin and Levin (2012) preform a metaanalys of 32 defense-growth relationship studies.

the results. In Section 5, I describe one potential explanation for the study's counterintuitive finding that military and civilian patents diffuse at similar rates. Section 6 concludes.

4.2 Military R&D, Innovation, and Diffusion: A Review

4.2.1 Military R&D and Innovation

Mowery (2010) proposes three channels by which defense expenditure can affect civilian innovation.[36] First, military R&D expenditure may fund institutions or researchers engaged in activities that enhance civilian innovation. Holding other factors constant, if military spending results in the dedication of more aggregate resources to innovation-directed ends than would be allocated in the absence of such funding, such expenditure can be expected to enhance civilian innovation. Illustrative of this mechanism is the contribution of Cold War-era military funding to the growth in research productivity of the American university system. According to Mowery, "Defense-related research spending contributed to the creation of a university-based US 'research infrastructure' during the postwar period that has been an important source of civilian innovations, new firms, and trained scientists and engineers" (Mowery 2010: 1237).

Second, defense spending can result in civilian innovation by increasing demand for new technologies through government procurement. Procurement can drive civilian

[36] Others, such as Goolsbee (1998) and Lichtenberg (1984; 1989), posit the effect of government spending on R&D on aggregate innovation to be, at least in the short term, negative. For example, Lichtenberg (1984; 1989) contends that US federal military spending crowds out innovation in other sectors. That is, by increasing demand for scarce, and supply inelastic, science inputs (e.g., researchers, labs, and equipment), military R&D expenditure will drive up the prices of these inputs causing civilian firms at the margin to forgo R&D.

innovation in several ways. For one, Lichtenberg (1984) observes that firms, attempting to win lucrative government contracts, may increase R&D spending. Large government purchases may also allow producers to realize scale economies, increase product performance, and spur process innovation within the production process. Empirical evidence for the civilian innovation-promoting effect of procurement has been found in Boston's high-tech sector (Dorfman 1983), the semiconductor industry (Mowery 2010), and even in the establishment of early American manufacturing processes following the government's procurement of rifles from the New England armory in the 18th century (Ruttan 2006; Bessen 2015).

Finally, defense R&D expenditure can drive overall innovation by producing knowledge and technologies that themselves go on to enhance subsequent innovative outputs.[37] No innovation begins "from scratch," rather every innovation depends on the knowledge and technology base available to the inventors during the innovation process. If military R&D expenditure increases the size of this base, it may spur subsequent innovation.

[37] Mowery conceptualizes this third channel in terms of "spinoff" or the entry of a military technology into civilian products or markets. However, I contend that the notion of diffusion more fully captures the manner in which the knowledge and technologies generated by defense R&D influences civilian innovation. First, spinoff refers to a mono-directional interaction. While the military-to-civilian interaction (i.e., spinoff) is indeed the primary one of concern, military-to-military knowledge transmission can strengthen the civilian innovation system by strengthening the overall innovative capacity of defense-servicing firms. Indeed, even intra-firm knowledge transmission should not be ignored; Hall et al. (2000; 2005) find that self-citations in a firm's patenting is a robust predictor of a firm market value. Diffusion, as operationalized here using the forward patent citations accumulated by military technologies, captures all of these interactions. Second, spinoff has traditionally been studied at a fairly high level of systems integration (i.e., it is typically final products that are studied). By considering products, rather than their subcomponents, it is likely that a large number of interactions are omitted. Diffusion evades this potential measurement problem by considering technologies at the level of the patent.

However, “units” of knowledge and technology vary in regards to the extent to which they influence subsequent innovation. In the realm of military-funded technologies, the Internet and semiconductors have spurred a large number of subsequent innovations, while light-water nuclear reactors and stealth technology have not. Thus, the influence of military-funded knowledge and technologies on subsequent innovation will depend not merely on the “quantity” of knowledge and technology produced by military funding, but it will depend on the extent to which these outputs diffuse within and outside of the system in which they originate.

4.2.2 The Diffusion of Military Technology

A review of the literature on the diffusion of military technology reveals two principal schools of thought. The prevailing scholarly view (Alic et al. 1992; Peck and Scherer 1962; Mowery 2010; 2012) is that the diffusion of military technology is bound to be low due to idiosyncratic features of modern national defense innovation systems. According to this view, the distinctive culture, policy environment, and market structure of the defense-servicing sector impede the diffusion of technologies developed therein. A second, more recently elaborated, school posits military technology diffusion to depend on the type of organizations involved in its development or the prevailing intellectual property rights (IPR) regime. This literature, developed through consideration of particular technology cases, contends that diffusion will occur more readily when firms rather than government agencies are involved in a technology’s development (Bellais and Guichard 2006), when technologies are developed by firms already experienced in technological development

(Acosta et al. 2011; 2013), and when IPR protection is strong (Bellais and Guichard 2006). This section reviews both schools of scholarship in order to extract testable claims.

The prevailing scholarly understanding – what Cowan and Foray (1995) refer to as the "standard view" – of the impact of defense technologies on the larger innovation system holds that certain unique features of the defense sector limit diffusion (Cowan and Foray 1995: 851). In one of the most thorough treatments of the modern civilian-military technology nexus, Alic et al. (1992) advance this position.[38] The authors contend that the military and commercial innovation systems should be viewed as "two coupled but largely distinct systems – one financed and managed by government, the other funded by and responsive to private markets" (Alic et al. 1992: 43). According to the authors, these systems are characterized by two distinctive cultures that vary on at least seven dimensions: impetus for design, nature of response, product cycle duration, priorities, production, R&D and production linkages, and technology sharing (Alic et al. 1992: 44).[39] For example, the impetus for product design in the civilian system is driven by firms' iterative feedback relationship with consumers, whereas design in the military realm is largely requirements driven and involves less producer-customer interaction. In regards to product life cycle duration, the authors observe that in the civilian system, product cycles may last from one to a handful of years compared to the decades-long cycles characteristic of military technology products. Additionally, production within the civil system is typically high

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[38] While Alic et al. focus on the US, the characteristics of the military system that are purported to limit diffusion (e.g., distinctive cultures, defense-specific policies, and monopsony) are present in other major national defense industries.

[39] While they do not use the term, the authors' descriptions of the civil and military cultures represent ideal types. In fact, the authors are careful to point out that certain civil activities (e.g., the building of oil refineries or utilities) resemble the military culture and certain military activities (e.g., the mass-production of ordinance) possess traits associated with civilian production.

rate/high volume, while that in the military system is low rate/low volume. The effect of distinctive military and civilian innovation cultures, according to the authors, is to limit "opportunities for synergy" or, in the language employed here, to limit military-civilian technological diffusion (Alic et al. 1992: 44).

Besides distinctive cultures, Alic et al. (1992) argue that specific defense policies result in the segregation of military and civilian innovation systems.[40] Such policies prevent military-civilian diffusion in three primary ways: by limiting the flow of information between systems, by changing the nature of technologies pursued by defense-servicing firms, and by adding substantial operating costs that limit the entry and exit of new firms from the defense servicing sector. In regards to limiting information flow, defense-technology export controls, the classification system, and rules concerning the ownership of intellectual property developed under defense contracts each serve to limit the diffusion of knowledge from within the military system.

Second, defense policies regarding product performance can also limit military-to-civilian technology flows. Specifically, Alic et al. (1992) contend that the high-performance requirements in defense product procurement contracts price out potential civilian buyers. This contention is supported by research that finds that defense-funded products rarely enter commercial markets without extensive modifications (Bellais and Guichard 2006; Alic 2007; Mowery 2012).

[40] Here again, the authors are careful to note that the segregation of civil and military systems is not complete. Actors for each system, for example, draw on the same technology and knowledge base.

Finally, diffusion is limited by policies that reduce firm turnover and create a relatively static ecosystem of defense contractors. The stringent accounting standards, cost accounting rules, disclosure requirements, and cost allotment rules that are requisite for defense servicing firms add substantial cost to firms operating in the defense system. Indeed, Dombrowski and Gholz (2006) characterize the ability to navigate US Defense Federal Acquisition Regulations as an, expensively acquired, "core competency" of defense servicing firms (Dombrowski and Gholz 2006: 139). These compliance costs create a barrier to firm entry into the defense innovation system. Firm exit – another potential source of diffusion – is limited by the incumbency advantage held by firms that have already developed the capacity to comply with the administrative burden of defense contracting and the government's imperative to maintain sufficient domestic military capacity to surge development or production should need arise.

In addition to defense policies that create barriers between military and civilian actors, other researchers (Peck and Scherer 1962; Mowery 2010; 2012) have focused on the manner in which the nonmarket context in which defense innovation occurs limits diffusion. Whereas in the civilian sector, diverse and autonomous end-users and suppliers provide technology developers with multiple sources of feedback, the producer/customer relationship within defense procurement proceeds through bi-lateral iterations in which the buyer primarily determines product specifications. This results in a relatively closed feedback system comprised of few actors and, thus, little diffusion.

The prevailing scholarly view, that the unique character of the military innovation system limits diffusion vis-à-vis the civilian system, can be formulated as the following testable claim:

H1: Military technologies will diffuse less readily than otherwise comparable civilian technologies.

More recently, research on how defense technology affects overall innovation has underscored heterogeneity in impacts. In particular, it has been argued that the propensity of a military technology to diffuse will depend on the nature of the organizations responsible for its development. Relative to government agencies, firms, it is argued, have the incentive and capacity to commercialize defense technologies (Winebrake 1992; Alic et al. 1992; Bellais and Guichard 2006). DeBruin and Corey (1988) study government-to-civilian technology transfers and find that government research agencies are often unaware of the commercial value of the technologies they develop. Firms, on the other hand, have both the incentive to commercialize these technologies and established channels by which to receive and transmit information outside of their organization. The contention that firm-developed military technologies will outpace their government-developed counterparts in regards to diffusion can be expressed as follows:

H2: Military technologies developed by firms will diffuse more readily than those developed by government agencies.

However, theory is not unambiguous in regards to the relative diffusibility of government versus privately held patents. Firms may find it advantageous to exploit a patented technology at a level below the social optimum. For example, firms may forgo licensing to competitors. Similarly, firms with monopoly power may chose not to use their patents (or limit licensing) in order to prevent new firm entry and maintain market power (Gilbert and

Newbery 1982). Less concerned with profits or the maintenance of market power, government patent-holders may, in contrast, encourage wider use of their IP. If this alternative logic were to prevail, government-held patents would diffuse more readily than those developed by firms.

It has also been posited that military technologies developed by organizations possessed of greater technological experience (measured by an organization's patent stock) will tend to be characterized by greater diffusibility. Advancing this claim, Acosta et al. (2011; 2013) contend that organizations with greater technology development experience will tend to produce less specialized technologies and that such technologies, when compared to specialized ones, have a greater range of technologies into which they may diffuse. The authors summarize this position as follows, "It is to be expected that those companies familiar with patent generation will have a greater propensity for developing technology liable to be used for multiple purposes, including civil patents" (Acosta et al. 2013: 13). To test this assertion, the following hypothesis is suggested:

H3: The diffusion of military technologies will relate positively to the technological experience of the organizations by which they are developed.

Finally, while profit-seeking firms have a clear incentive to commercialize defense-funded technologies, their ability to do so may depend on the possession of enforceable property rights on the technologies in question. Bellais and Guichard (2006) contend that establishing an "intellectual property rights (IPR) culture" within the defense sector is critical to stimulating the transfer of military technology into the civilian sector (Bellais and Guichard 2006: 274). The authors cite the 1992 US Technology Reinvestment Program

(TRP) as exemplary of how granting intellectual property rights to firms that participate in defense technology development may spur defense technology diffusion. In particular, the authors cite the high rate of commercialization of the projects developed under the auspices of the TRP and the increased participation of civilian-facing firms such as Hewlett Packard and IBM as illustrative of the diffusion-enhancing potential of IPR. The claim that stronger IPR protection will facilitate the diffusion of military technology can be articulated as follows:

H4: *The diffusion of military technologies will relate positively to the strength of the IPR regime in which they are developed.*

While scholars of military technology innovation predict IPR regime strength to correlate positively to the diffusion of military technology, economic theory more generally is ambivalent regarding the relationship between IPR protection and diffusion (Encaoua et al. 2006; Woo et al. 2015). On one hand, the information disclosure portion of the patenting process may promote diffusion by increasing access to the knowledge used to produce a given innovation. Indeed, this disclosure requirement is explicitly designed to promote the diffusion of information (Rockett 2010). On the other hand, strong IPR protection may incentivize the use of patenting to prevent market entry (i.e., strategic patenting), which may, in turn, limit diffusion (Neuhäusler 2012).

4.3 Data and Methods

To investigate the hypotheses enumerated above requires information on the diffusion of military technologies, the diffusion of civilian technologies, patent characteristics, patent assignee characteristics, and IPR protection. Towards this end, I construct a dataset containing this information for 17,735 patent families over the period 2006-2010 (inclusive).[41] These patent families comprise of inventions granted by over 40 national patent agencies. Table 6 summarizes the data employed in this study. Sections 4.1 and 4.2 define the construction of the variables used here and Section 4.3 describes the model.

Table 5 Descriptive Statistics, full sample

Descriptive statistics, full sample

Variable	Obs.	Mean	Std. dev.	Min.	Max	Source
Dependent Variable						
Forward Citations	17,753	2.32	4.81	0	200	Thomson Reuters
Independent Variables						
Military Technology[a]	17,753	0.12	0.32	0	1	Derwent
Government Assignee[a]	17,753	0.15	0.35	0	1	Derwent
Technological Experience	17,753	1538.16	1230.29	40	5,408	Derwent
IPR protection[b]	14,394	4.72	0.32	3.425	4.875	Park (2008)
Control Variables						
No. of Derwent Codes	17,753	2.42	1.36	1	13	Derwent
Backward Citations	17,753	13.72	27.50	1	662	Derwent
No. of patent family jdx.	17,753	2.98	2.72	1	58	Derwent

[a] Dummy variable, [b] The Ginarte and Park index measures IPR on the country level. Thus patents with a home jurisdiction of the Patent Cooperation Treaty or the European Patent office are not included in the regressions using the Ginarte and Park IPR index.

[41] Patent families refer to the group of patents filed for the same invention within more than one jurisdiction. The use of patent families is preferable to that of patents because it prevents double counting of inventions that have been filed in multiple jurisdictions. The cutoff point of 2010 is used to assure data quality. Because forward citations are accumulated after a given patent is approved, forward citation counts will tend to increase in relation to time. However, research suggests (Trajtenberg 1990; Lanjouw and Schankerman 2004) that the preponderance of citations accumulate during the first five years after a patent's approval.

The majority of military technological innovation is concentrated within a small number of large diversified firms (Brooks 2007). Besides their defense servicing operations, these firms (e.g., Raytheon, Lockheed Martin, Saab) typically also have large civilian-facing operations. Indeed, Alic et al. (1992) observe that for firms with business units specializing in defense technologies, the vast majority of sales are generated within the civilian sector and note that, "defense-dominated business units are almost without exception embedded in much larger firms dominated by commercial markets" (Alic et al. 1992: 361). More recently, Thompson (2011) observes that defense firms facing uncertain budget conditions have sought to diversify info civilian markets. Because testing H1 requires comparing rates of diffusion for *otherwise similar* civilian and military patents, the fact that the entities responsible for most military patenting also patent in the civilian sector can be leveraged to reduce the possibility of unobserved firm or industry-specific heterogeneity in diffusion. The data used here is thus all patents filed by the top 35 military patent filing organizations during the period of concern. A detailed description of the sampling strategy and a full list of the 35 organizations included in the analysis are provided in Appendix A.

4.3.1 Dependent Variable

Technological Diffusion: In defining technology diffusion, I begin with Rogers' (2003: 11) definition of diffusion as the process by which an innovation is transmitted across members of a social system over time. However, within Rogers' framework "innovation" is defined broadly to include technological, organizational, and process innovations. Indeed, scholars of the diffusion of innovation within or across militaries typically couple the diffusion of technologies with that of practice (Rosen 1994; Goldman and Eliason 2003; Horowitz 2010). However, in this chapter, I focus exclusively on the former or, in the parlance of Goldman and Eliason (2003: 8-9), on the diffusion of military "hardware" rather than the "software" of doctrine, tactics, or organization. There are two reasons for this distinction. First, coupling technological and doctrinal innovation is to introduce endogeneity into a single dependent variable. That is, as was discussed in chapter 2 technological change drives change in doctrine (Blasko 2011; Murray and Millett 1998). The converse also holds up to empirical scrutiny. For example, Blasko finds that the United States' doctrinal requirement to maintain its global alliance commitments drove the development of the Conventional Prompt Global Strike missile and the X-37B unmanned spacecraft (Blasko 2011: 357). The existence of causal links between two dimensions of the object under scrutiny makes isolation of the true path of action logically indeterminate. Second, the existence of rich and validated data sources and established statistical techniques make investigation of technological diffusion tractable. The absence of such metrics for more elusive types of knowledge-flows complicates their interrogation using statistical methods. Narrowing the scope of Rogers' definition allows technological diffusion to be defined here as the process by which a technological innovation is transmitted across members of a social system over time.

Technological diffusion is operationalized here using period counts of forward patent citations. Forward citation counts refer to the number of instances that a given patent has been cited in the "prior art" section of subsequent patent applications.[42] Forward

[42] When filing a patent, the patent applicant and the examiner are required to cite previous patents that reveal the state of the art for the technology seeking protection. This process verifies the novelty of the claim and defines the scope of protection.

citations thus measure the extent to which a given invention has transmitted across subsequent technologies by subsequent patent assignees. The use of forward citations to measure technological diffusion is widespread in the innovation literature (Hoetker and Agarwal 2007; Sorenson and Fleming 2004; Verdolini and Galeottib 2011) and has been validated using firm-level survey data on technology use dispersion (Duguet and MacGarvie 2005). The forward citations count data used here are from the Thomson Reuters Patents Citation Index, which, for a given patent, aggregates the forward citations received by subsequent patents filed at six patent agencies: United States, Germany, Japan, Great Britain, the Patent Cooperation Treaty, and the European Patent Office. For each observation, forward citation counts were matched to their associated patent families using the Derwent Primary Accession Number (a unique record identifier).

Figure 2 provides a visualization of the forward citation process for two patents from the sample. Both patents were filed in 2010, the first (US2010259607-A1) by Raytheon and the second (US2010290487-A1) by the US Secretary of Navy. In the ensuing years, the first patent was cited one time by subsequent patents; the second patent was cited three times. Thus, the forward citations count variable for the first observation is one, while that for the second is three.

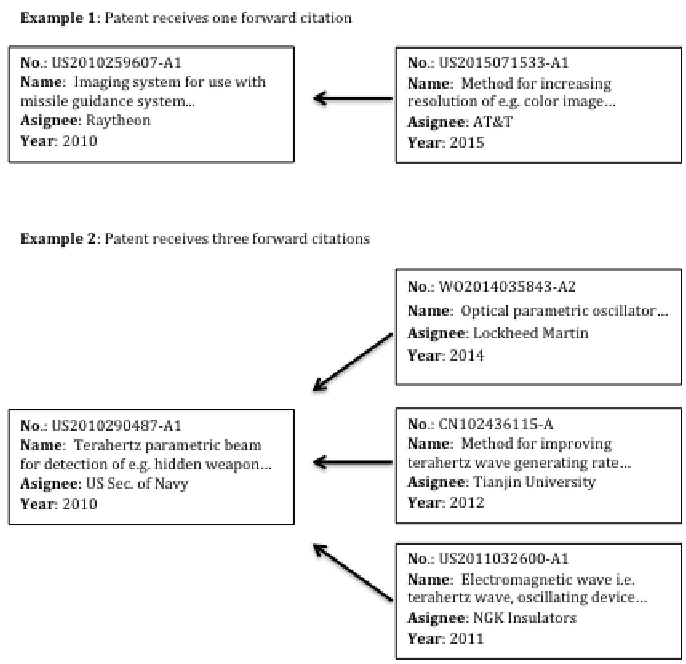

Figure 2 Diffusion as measured by forward patent citations

4.3.2 Independent Variables

Military Technology: In testing H1, I distinguish military patents from civilian patents using the Derwent technology classification system.[43] The Derwent categories are preferable to other classification schemes such as International Patent Classification (IPC) for three primary reasons. First, IPC codes do not distinguish between military and civilian technologies. For example, filtering patents using IPC code F41 (Weapons) would include a Sega Corporation patent for an electronic dart game (WO2006070875-A1). Second, using

[43] In particular, patents are first filtered using Derwent Class Code "W07" (Electrical Military Equipment and Weapons).

either IPC code F41 (Weapons) or F42 (Ammunition; Blasting) omits non-weapons military technologies such as defensive, command and control, and military transport systems. Finally, the Derwent categories are hand curated by subject matter experts at Thomson Reuters.

The 35 organizations examined here produced 2,112 military patents from 2006-2010. These patents represent a wide range of offensive and defensive military technologies. For example, the sample includes: a Raytheon patent for a drone-to-drone refueling system (US2010321011-A1), a Northrop Grumman patent for the radar used in the E-8 joint surveillance target attack radar system (STARS) aircraft (US2006232463-A1), a Thales patent to protect aircraft from incoming homing missiles by creating a plasma filament (WO2006134050-A1), a US Secretary of the Navy patent for an electromagnetic pulse delivery system (US7475624-B1), and a Korean Agency for Defense Development patent for a dual barrel firearm (KR915857-B1).

Government Assignee: To test whether patented military technologies owned by government agencies diffuse less than those developed by firms (H2), I define a dummy variable that takes the value of one if a patent has a single assignee and that assignee is a government agency. Of the 2,112 military patents in the sample, 421 were filed by a single assignee from a government agency.

Technological Experience: To determine whether the technological experience of a military patent's assignee is associated with greater diffusion (H3), I proxy technological experience using each organization's total patent output during the period of concern. This measure, proposed in Acosta et al. (2011, 2013), intends to capture an organization's overall technological and patenting experience, as opposed to its military technology experience. During the period in question, this measure ranged from 40 (Taser International) to 4,763 (Boeing).

Intellectual Property Rights: In order to evaluate whether the strength of a country's IPR protection is associated with greater diffusion of its military technologies (H4), I use the Ginarte and Park index of patent rights for the year 2005 (Park 2008). The index is calculated as the sum of a country's scores on five dimensions of IPR protection: the breadth of inventions covered, the strength of enforcement mechanisms, international treaty membership, legal provisions for loss of protection, and the duration of protection. A country's score on each dimension ranges from 0 to 1; thus the index ranges from 0 to 5. For each patent, the Ginarte and Park index score is assigned based on that patent's basic patent country (i.e., the country in which the patent was first published).

Control Variables: In addition to the main independent variables, the models presented below include a set of patent-level variables to control for other factors that may influence diffusion. First, I control for the breadth of the technological coverage of the patented invention using the number of Derwent Classification Codes that have been assigned to a given patent. Inventions with wide technological coverage have greater opportunities to diffuse than those spanning fewer subclasses. Second, I control for the size of the technological domain into which the patent is entering using the number of backward citations contained in the prior art section of the patent documents. When filing a patent, applicants are required to cite as prior art all patents and scientific references that are relevant to the invention's claim of novelty. Thus, the size of the prior art section is a useful proxy for the size of the technological domain into which the patent is entering (Lanjouw and Schankerman 2002). Large technological domains comprise a large number of inventors working on related technologies and thus increase the propensity of a given patent to diffuse. Third, I control for each patent's jurisdictional coverage. Patents filed in multiple jurisdictions have been found to be of higher quality than those filed in a single jurisdiction (Sampat 2005). Because high quality innovations are assumed to diffuse more readily than low quality ones, each patent's jurisdiction count is added to the model. Finally, I introduce a set of patent application year dummy variables to control for inter-temporal variation.

4.3.3 Model

Count data (i.e., data with values that are nonnegative and discrete) suggests the use of Poisson models (Hoffman 2004). However, in the Poisson distribution the mean is equal to the variance. Poisson models thus fix the dispersion parameter (alpha) at zero. Negative binomial models, in contrast, allow the dispersion parameter to take a random value and are thus preferred to Poisson models when the data are overdispersed (Cameron and Trivedi 2013). Because forward citations are characterized by overdispersion (the variance of 23.09 is greater than the mean of 2.32), a negative binomial regression model is estimated.[44] The positive value of the alpha parameters, reported in Tables 7-8, confirm that negative binomial regression is preferable to Poisson models in the present empirical setting. Robust standard errors are used to correct for heteroskedasticity.

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[44] More precisely, I estimate what Cameron and Trivedi (2013) refer to as the mean-dispersion negative binomial model or "NB2" in the authors' terminology.

Besides overdispersion, the data are also characterized by excess zeros; 7,682 (43%) patents accumulated zero citations. Thus zero-inflated negative binomial models (ZIBN) are also estimated and presented in Appendix B. The results of the ZIBN in regards to the hypotheses tested here mirror those of the negative binomial models presented below.

As H1 requires the comparison of military patents to civilian patents, the full sample is used in model 1. The remaining hypotheses refer to characteristics unique to military technologies and thus models 2-4 use only the military technology patents. To ensure that the results are not driven by a country-level outlier (for the period in question, patents assigned to US entities represent 56.59% of observations), the models are estimated using both the full sample and the US-excluded sample. Finally, to verify that the results are not sensitive to patent-level outliers (i.e., patents with a very high number of citations), the models are also run using a sample that excludes all patents with more than 30 forward citations.

4.4 Results

Table 7 presents the results of the negative binomial models predicting diffusion for the full sample. Table 8 presents the results of the same model fit to the US-excluded data. These tables present unstandardized parameter estimates, which are interpreted as the predicted change in the log of forward citations. This allows the provided coefficients to be interpreted as semi-elasticities: for a one unit change in the predictor variable, there is a one percent change in forward citations equal to the value of the coefficient for that variable

(Hilbe 2011: 130). Robust t-statistics are provided in parenthesis. Table 9 summarizes the results of the hypothesis tests for the full and US-excluded samples. In general, the analyses provide ambivalent support for prevailing scholarship on the diffusion of military technology.

Table 6 Negative binomial regression of diffusion, 2006-2010, full sample

Negative binomial regression of diffusion, 2006-2010, full sample

	1	2	3	4
Military Tech (Dummy)	-0.0315			
	(-0.70)			
Single Gov. Assignee (Dummy)		-0.0549		
		(-0.52)		
Tech. Experience			0.000129***	
			(3.58)	
IPR				1.087***
				(6.85)
Tech. Breadth	0.0449***	0.0622*	0.0597*	0.0594*
	(3.96)	(2.37)	(2.23)	(2.03)
Tech. Domain	0.0141***	0.0239***	0.0237***	0.0190***
	(15.86)	(5.46)	(5.16)	(4.18)
Jurisdictional Coverage	0.0703***	0.0482**	0.0489***	0.0387*
	(14.52)	(3.28)	(3.57)	(2.54)
Year Dummies	YES	YES	YES	YES
Constant	0.610***	0.418**	0.268	-4.594***
	(13.25)	(2.90)	(1.92)	(-6.30)
Wald χ^2	1226.79	127.80	140.49	144.54
Alpha	1.89	1.83	1.80	1.78
Log pseudolikelihood	-33448.85	-3987.16	-3979.70	-3104.83
Observations	17,735	2,112	2,112	1,697

All coefficients are unstandardized. Robust t statistics in parentheses, * p<0.05, ** p<0.01, *** p<0.001

Table 7 Negative binomial regression of diffusion, 2006-2010, US-excluded sample

Negative binomial regression of diffusion, 2006-2010, US-excluded sample

	1	2	3	4
Military Tech (Dummy)	-0.109			
	(-1.68)			
Single Gov. Assignee (Dummy)		-0.0969		
		(-0.57)		
Tech. Experience			0.000193***	
			(3.34)	
IPR				-0.231
				(-1.21)
Tech. Breadth	0.0724***	0.0945*	0.0919**	0.194***
	(3.37)	(2.53)	(2.60)	(4.05)
Tech. Domain	0.0159***	0.0231**	0.0208**	0.0399***
	(7.78)	(2.97)	(2.70)	(4.20)
Jurisdictional Coverage	0.148***	0.137***	0.132***	0.128***
	(17.78)	(5.47)	(5.46)	(4.12)
Year Dummies	YES	YES	YES	YES
Constant	-0.253**	-0.604**	-0.709***	-0.436
	(-3.22)	(-3.08)	(-4.34)	(-0.56)
Wald χ^2	1015.97	99.21	146.21	88.30
Alpha	1.83	1.57	1.52	1.54
Log pseudolikelihood	-12444.20	-1655.68	-1650.22	-799.50
Observations	7,698	1,053	1,053	638

All coefficients are unstandardized. Robust t statistics in parentheses, * p<0.05, ** p<0.01, *** p<0.001

Of the hypotheses tested here, the most theoretically and empirically grounded is the contention that relative to comparable civilian technologies, military technologies will diffuse less readily (H1). However, when this claim is tested in a large sample setting, it is not supported by the data. In both sample conditions, the average rate of diffusion of a military patent is not statistically different from that of a civilian patent. While excluding US patents from the sample increases both the magnitude of the military-civilian diffusion differential and the associated t-statistics, the difference remains statistically indistinguishable from zero at the 0.05 level.[45]

[45] It is nevertheless intriguing that the parameter estimate for the military technology dummy variable and the associated t-statistic increase upon omitting the US patents. This supports the contention by Bellais and

The data also fail to support hypothesis 2. That is, there is no evidence that patents assigned to government agencies diffuse less readily than those assigned to private entities. While not shown in Tables 2-3, I also test whether patents with *at least* one government assignee diffuse at different rates than patents with no government assignees. In both sample conditions, the estimates for this alternative definition of government participation were not significant. In summary, I find no evidence to support the claim that patents assigned to government agencies, either as a co-filer or as the sole assignee, diffuse less readily than patents filed by private entities.

Of the hypotheses tested here, the contention that an assignee's technological experience will increase the diffusibility of its patents (H3) fared best. In both sample conditions, an organization's technological experience was a positive and significant predictor of the diffusion of its military patents. However, when a set of regressions were run using only US patents, the technological experience variable turns negative and is significant at the 0.05 level.[46] This suggests that non-US patents drive the full sample result and that the assumption that firms' technological experience relates positively to the diffusion of its patents should be reexamined in the US context.

The strength of the IPR regime in which a patent is filed is a significant positive predictor of diffusion in the full sample, yet not in the US-excluded sample. Once US patents are omitted, the IPR variable turns negative. Indeed, in the zero-inflated negative

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Guichard (2006) that the US does a better job than most countries in linking defense and non-defense sectors.

[46] In the US-only setting, the results regarding H1 and H2 hold. H4 cannot be tested using a single country because of the lack of variation in the Ginarte and Park IPR score.

binomial specification (presented in Appendix B), the IPR variable in the US-excluded sample is both negative *and* significant.

The observation that IPR regime is positive and significant in the full sample can likely be explained by the exceptional nature of the US in the present empirical setting. In the 2005 Ginarte and Park index, the US received the highest rating of any country (4.875 out of 5). US patents also diffuse more readily than patents from most other countries.[47] Thus, the significance of the IPR measure in the full sample likely owes to the large number (56.59% of the sample) of US patents in the sample.

While the high diffusibility of US patents and the high Ginarte and Park score assigned to the US appear to explain the positive IPR/diffusion correlation in the full sample, the negative relationship between IPR strength and the diffusibility of military patents in the US-excluded sample requires further explanation. As mentioned in Section 4.2, theory yields ambivalent predictions regarding the relationship between IPR protection and diffusion. The ambivalence of the tests for H4 suggests that further empirical investigation into the role of IPR strength on military patent diffusion may be warranted. Given the wide variation of national IPR protection with respect to time in countries such as Russia and China, time series analysis of patterns of diffusion may prove useful towards this end.

None of these results are sensitive to patent-level outliers. While not presented here in consideration of space, estimating each of the models using a sample that excludes

[47] The exceptions here are patents filed in the UK and those filed under the PCT, each of which on average accumulate an higher number of forward citations than those of the US.

highly diffused patents (i.e., those with more than 30 forward citations), does not change the results of the hypotheses tests. Indeed, the proportion of highly diffused patents to total patents is roughly equivalent for military and non-military patents.[48] Of the 70 patents that accumulated 30 or more forward citations, eight (0.038% of the total) were military while 62 (0.040%) were civilian.

Finally, it should be noted that the control variables are positive and significant in all models. This suggests that a patent's technological coverage, technological domain, and jurisdictional coverage are all positive predictors of both overall technological diffusion and that of military technologies. Table 4 summarizes the results of the four hypothesis tests at the 0.05 level.

Table 8 Results summary, hypothesis tests

Results summary, hypothesis tests

	Full Sample	US excluded
Hypothesis 1: The diffusion of military vs. civilian tech.	Not supported	Not Supported
Hypothesis 2: Private vs. Gov. patents	Not supported	Not Supported
Hypothesis 3: Technology Experience	Supported	Supported
Hypothesis 4: IPR Regime	Supported	Not Supported

Note: Hypothesis testing based on models containing the full set of control variables. Based on the 0.05 level of significance.

4.5 A Potential Underlying Mechanism

Section 4.2 described in some detail the contention that features particular to the defense innovation system impede the diffusion of the knowledge and technologies developed therein. The finding that military and civilian technologies diffuse at similar rates appears

[48] Removing the highly diffused patents leaves 17,665 observations for the test of H1, 2,106 observations for the test of H2-H3, and 1,692 observations for the test of H4.

to challenge this claim. However, the presence of many of the features proposed to limit diffusion (e.g., export controls, the classification system, and the monopsonistic nature of defense procurement) is undeniable. That at least some of these features would inhibit knowledge flows seems uncontroversial and indeed has been documented empirically (Alic et al. 1992). The simultaneous presence of barriers to knowledge flows and the absence of evidence of a military-civilian diffusion gap suggests the possibility that some compensatory mechanism is operating. That is, some attribute of military technologies may allow their diffusion despite barriers to knowledge flows. Ruttan (2006a; 2006b) suggests one such attribute: the disproportionately general-purpose character of military-funded technologies.

In *Is War Necessary for Economic Growth?* Vernon Ruttan begins by noting the strong historical linkage between states' technological demand during military conflict and technological change; observing that the cylinders in steam-powered engines could initially only be bored using mils developed to bore cannon and that demand from the French Navy in the 1780s drove the development of early French capacity in ferrous metallurgy. The majority of Ruttan's focus, however, is on the influence of defense investment on postwar US innovation. Specifically, Ruttan (2006b) traces the contribution of defense R&D to six general-purpose technologies – aircraft, the computer, the Internet, nuclear power, semiconductors, and satellite communication technologies – and concludes that absent defense funding the appearance of each technology would have been significantly delayed. Indeed, Ruttan constructs counterfactuals whereby he attempts to estimate the date of advent of each technology absent military funding. In each case, counterfactual analysis suggests significant delay. For example, Ruttan estimates that without military funding, the first Internet browser (in reality invented in 1990 by Tim Berners-Lee), would not have debuted until 2002 (Ruttan 2006b: 196).

However, Ruttan's claim is not merely that induced technical change *may* proceed via military demand but rather that military demand is *indispensable* in producing general-purpose technologies. In other words, the private sector alone, will not produce, or at least will under-produce, general-purpose technologies. In reaching this conclusion, Ruttan evokes two mechanisms: a particular market failure associated with investment in general-purpose technologies and the distinct time horizons used by private and public actors. First, Ruttan claims that the gains associated with general-purpose technologies are so disperse so as to make their capture by a single firm impossible. Thus no single firm will have sufficient incentive to make the large investment necessary to develop the next general-purpose technology.[49] This basic argument structure, that public investment in R&D corrects for a market failure associated with the difficulty associated with privately appropriating the returns to investment in research, traces to Nelson (1959) and Arrow (1962); Ruttan adopts it to the setting of defense R&D. Second, Ruttan observes that general-purpose technologies have typically involved decades-long periods of continuous funding and is skeptical of the private sector's capacity to provide such "patient capital" (Ruttan 2006b: 177).

[49] Ruttan acknowledges that under certain circumstances – he cites conditions of low international competition and policy-enabled monopoly – the private sector may adopt a time horizon of sufficient duration to undertake the basic research necessary to spawn general-purpose technologies. However, he agues that such circumstances are increasingly rare and finds it "difficult to anticipate that the private sector, without substantial public support for research and technology development, will become an important source of new general-purpose technologies over the next several decades (Ruttan 2006b: 178).

General-purpose technologies, by definition, will have large effects on subsequent innovation.[50] In other words, the diffusion of these technologies, and their underlying knowledge, will be high. It is thus possible that the failure to observe diffusion-inhibiting effects of the barriers to diffusion in the military sectors is explained by the high diffusibility of a subset of the military technologies that have been considered here. This is, of course, a testable claim and one that merits further investigation. Such investigation is undertaken in chapter 5 of this dissertation.

The next chapter of this dissertation attempts, *inter alia*, to investigate this claim. By examining whether there are significant differences in the characteristics of patents produced by different organization types – universities, firms, and government research agencies – chapter 5 of this dissertation offers evidence that is useful in evaluating Ruttan's claim and the plausibility of the potential underlying mechanism described above. In particular, chapter 5 offers evidence that patents developed by government research agencies are significantly more general than those developed by firms. This supports Ruttan's argument that governments have a comparative advantage vis-à-vis firms in the development of general purpose technologies. Additionally, the observation that the technologies developed by government research agencies are particularly general supports an explanation of the null results presented here that is based on the existence of a countervailing factor. In particular, the findings of chapter 5 support the notion that the

[50] Bresnahan and Trajtenberg (1996) argue that general-purpose technologies can be defined based on the possession of three traits: pervasiveness, showing improvement over time, and the ability to spawn subsequent innovations.

particularly general character of the underlying innovations may mitigate the barriers to diffusion that exist within the military innovation system.

Relative to their participation in civilian innovation, government agencies are disproportionately likely to participate in the development of military technologies. Government patents, compared to a random sample of civilian patents, are thus over-represented in the sample used in this chapter. It is thus likely that the high participation of government actors coupled with the high generality of government-developed technologies explains the null result presented in this chapter.

4.6 Conclusion

In this chapter I have attempted to test some of the prevailing claims regarding the diffusion behavior of military technologies. The study's most striking result is that military and civilian patents diffuse at similar rates. This finding contradicts the contention that idiosyncratic features of the defense innovation system limit the diffusion of technologies developed therein. The failure to observe a significant difference in the diffusion behavior of civilian and military technologies suggests that the civilian-military "institutional segregation: observed by Alic et al. (1992: 134) may no longer be so pronounced. Further investigation into the character of the relationship between the military and civilian innovation systems thus appears to be warranted.

It is important that the policy implications of the presented results not be overdrawn. While it may be tempting to consider the results presented here as evidence that military investment in R&D has a greater than expected impact on overall innovation, the present study does not offer the means by which to evaluate the per dollar impact of various R&D spending options. While civilian and military patents appear to diffuse at similar rates, I do not account for the cost of producing the knowledge underlying these patents. It is possible, and indeed likely, that the cost of producing a given military patent differs from that of producing a civilian one. Any evaluation of the relative diffusion impact of an additional dollar of R&D would have to account for any such variation in the cost of producing innovation in the sector in question.

Finally, the research design employed here offers the means to test additional hypothesis regarding the diffusion of military technologies. Four hypotheses were tested here, yet the literature on military technology diffusion makes additional claims. I elaborate two of these additional claims in Section 6.3.2 of this dissertation. It is hoped that the methodological approach utilized here might prove to be a useful model for scholars interested in the evaluation of the claims contained in chapter 6.

4.7 Technical Details – Sampling Strategy

To arrive at the final set of 35 organizations, I begin with the top 50 military technology-patenting organizations. I omit organizations for which military patents represent a very small portion of total innovation activity (i.e., those for which military patents represent less than 5% of the firm's total patenting during the period in question). Such organizations (e.g., Samsung, IBM, GE, Toshiba, NEC) are omitted because they are predominantly civilian facing and thus do not constitute members of the purported military innovation system under scrutiny. Omitting such organizations leaves 35 organizations to be included in the analysis. Table 9 provides these organizations and the fraction of their total patenting occupied by military technology patenting.

Table 9 Organizations used in analysis, share of total patenting occupied by military technology patents

35 organizations used in analysis, share of total patenting occupied by military technology patents

Organization	Military Weapons Patents (% of Total)
Taser International Inc.	75.00%
Deut Franzoesisches Forsch Inst	62.16%
MBDA Uk Ltd.	57.45%
Inst Franco Allemand Rech Saint Louis	53.85%
Lfk Lenkflugkoerpersysteme Gmbh	49.38%
Diehl Bgt Defence Gmbh & Co Kg	38.42%
Instrument-Making Des Bur Unitary Enterp	34.79%
Giat Ind SA	32.43%
Exelis Inc.	30.93%
Nexter Systems	27.47%
Rheinmetall Waffe Munition Gmbh	27.12%
Rafael Advanced Defense Systems Ltd.	23.53%
Saab Ab	23.05%
Alliant Techsystems Inc.	21.01%
Krauss-Maffei Wegmann	20.83%
Rheinmetall Landsysteme Gmbh	19.53%
Raytheon Co.	18.78%
Russian Military Academy	15.15%
BAE Systems	14.89%
Rockwell Collins Inc.	12.40%
US Sec. of Army	12.17%
Lockheed Martin Corp.	11.99%
Ihi Aerospace Co Ltd.	11.70%
The Korean Agency of Defense Development	11.49%
US Sec. of Navy	10.95%
Bolotin N.B.	10.91%
Sagem Defense Securite	9.92%
ITT Mfg Enterprises Inc.	9.54%
US Sec. of Air Force	9.52%
Harris Corp	7.34%

Table #9 continued

Northrop Grumman Corp.	6.94%
Sun L	6.54%
Thales SA	5.85%
Eads Deut Gmbh	5.81%
Boeing Co	5.79%

4.8 Technical Details – Zero-inflated Negative Binomial Models

As a robustness check to the results presented in this chapter, I also estimate zero-inflated negative binomial (ZINB) models for diffusion. The results of the ZINB model for the full sample and the US-excluded sample are provided in Tables 11 and 12 below. The results are consistent with the negative binomial regressions presented in the paper's body.

The rationale for estimating a ZINB model partially mirrors that of fitting the negative binomial to the diffusion data. Namely, overdispersed count data suggest the use of the negative binomial model. The ZIBN, however, models the zeros in the data using two distinct processes. In particular, ZIBN models assume that a population's excess zeros are generated by a different process than is the rest of the count data (Green 1994). The excess zeros are modeled using a logistic regression, and rest of the data is fit using a negative binomial model.

The use of a two-stage model requires that theory suggest the existence of two distinct regimes or data generation processes. In the context examined here, the use of ZINB can be justified based on research suggesting that many patents represent only nominal innovations (Bessen and Meurer 2009). These patents are unlikely to accumulate any forward citations. The second distribution characterizes non-trivial innovations. Each process can generate zeros. I use the full set of control variables as the covariates in the inflation (logistic) model. The negative binomial stage includes the controls and adds the independent variables used to test hypotheses 1-4.

A Vuong test can be used to select between the ZINB and negative binomial models. In this case, such a test reveals the ZIBN to be preferable. However, because the presence of two distinct data generating process is open for debate, the more parsimonious, single-stage, model is presented in the paper's body. Nevertheless, the results of both specifications, in terms of the hypotheses tested here, are identical.

Table 10 Zero-inflated negative binomial regression of diffusion, 2006-2010, full sample

Zero-inflated negative binomial regression of diffusion, 2006-2010, full sample

	Logistic				Negative Binomial			
	1	2	3	4	1	2	3	4
Military Tech (Dummy)					-0.0149 (-0.41)			
Single Gov. Assignee (Dummy)						0.0505 (0.55)		
Tech. Experience							0.0000792* (2.54)	
IPR								0.844*** (6.31)
Tech. Breadth	-0.0641 (-1.74)	-0.0794 (-0.77)	-0.0869 (-0.81)	-0.119 (-0.63)	0.0261** (2.90)	0.0332 (1.27)	0.0308 (1.17)	0.0370 (1.14)
Tech. Domain	-0.296*** (-12.09)	-0.220*** (-4.66)	-0.220*** (-4.45)	-0.254* (-2.45)	0.00936*** (17.13)	0.0135*** (6.14)	0.0135*** (6.09)	0.0132*** (4.78)
Jurisdictional Coverage	-0.450*** (-6.20)	-0.359* (-2.57)	-0.357* (-2.55)	-0.310 (-1.39)	0.0434*** (10.92)	0.0267* (2.28)	0.0246* (2.20)	0.0240 (1.58)
Year Dummies	YES	YES	YES	YES	YES	YES	YES	YES
Constant	0.811*** (5.04)	1.066** (2.71)	1.061** (2.63)	0.712 (1.05)	0.969*** (24.73)	1.019*** (7.45)	0.944*** (6.79)	-3.026*** (-4.69)
N	17,735	2,112	2,112	1,697	17,735	2,112	2,112	1,697
LN α					0.364*** (17.29)	0.236*** (3.50)	0.239*** (3.54)	0.337*** (4.07)
LR χ^2 (8)	1471.19***	186.52***	192.79***	175.55***				

All coefficients are unstandardized, t statistics in parentheses, * p<0.05, ** p<0.01, *** p<0.001

Table 11 Zero-inflated negative binomial regression of diffusion, 2006-2010, US-excluded sample

Zero-inflated negative binomial regression of diffusion, 2006-2010, US-excluded sample

	Logistic				Negative Binomial			
	1	2	3	4	1	2	3	4
Military Tech (Dummy)					-0.107 (-1.92)			
Single Gov. Assignee (Dummy)						-0.0984 (-0.64)		
Tech. Experience							0.000182*** (3.65)	
IPR								-0.522* (-2.53)
Tech. Breadth	-0.116* (-2.29)	-0.128 (-1.21)	-0.141 (-1.30)	-0.182 (-0.97)	0.0408** (2.82)	0.0438 (1.21)	0.0407 (1.14)	0.163** (2.89)
Tech. Domain	-0.181*** (-6.15)	-0.104** (-2.79)	-0.101** (-2.78)	-0.0144 (-0.13)	0.0108*** (11.60)	0.0104** (3.17)	0.00885** (2.87)	0.0328*** (3.51)
Jurisdictional Coverage	-0.532*** (-5.09)	-0.349** (-2.83)	-0.351** (-2.82)	-13.35 (-0.03)	0.0863*** (13.64)	0.0686*** (3.93)	0.0677*** (4.13)	0.0864** (2.58)
Year Dummies	YES	YES	YES	YES	YES	YES	YES	YES
Constant	1.294*** (6.35)	1.525*** (3.91)	1.564*** (4.00)	13.86 (0.03)	0.428*** (6.20)	0.530** (2.60)	0.416* (2.22)	1.445 (1.63)
N	7,698	1,053	1,053	638	7,698	1,053	1,053	638
LN α					0.251*** (6.69)	-0.213 (-1.62)	-0.249 (-1.90)	0.00829 (0.05)
LR χ^2 (8)	994.11***	137.16***	150.55***	44.63***				

All coefficients are unstandardized, t statistics in parentheses, * $p<0.05$, ** $p<0.01$, *** $p<0.001$

CHAPTER 5. VARIATION IN PATENT IMPACT BY ORGANIZATION TYPE

5.1 Introduction

The results of the chapter 5 indicate, *inter alia*, that individual technological innovations vary dramatically in terms of their effects on subsequent technological progress. Certain innovations such as Cohen and Boyer's "Process for producing biologically functional molecular chimeras" (US4237224) have demonstrated enormous capacity for spurring subsequent scientific and technological progress (Azagra-Caro et al. 2017; Feldman and Yoon 2011). Others such as a "method of scoring a bowling game" (US6142880) have yielded no such bounty. Plainly, a society would prefer that a higher proportion of their innovations be of the former type. Thus the identification of reliable determinants of high impact technological innovations would appear a worthwhile endeavor. This chapter considers whether the type of organization that develops an innovation constitutes one such determinant. More precisely, in this chapter I test whether the technological innovations developed by three types of organization—firms, universities, and government research agencies—vary in regards to their effect on subsequent technological progress.

The innovation-generating effects of Cohen and Boyer's contribution were both large and wide reaching.[51] In the parlance of patent citation analysis, the innovation was both *important* and *general*. In the investigation to follow, I consider the effect of

[51] As of December 18, 2017, according to Google patents, patent US4237224 had received 451 citations. The mean number of forward citations in the sample is 1.24. The breath of US4237224's citations is chronicled in Feldman and Yoon's (2011) article.

organization type on these two dimensions. Importance refers to how frequently a technology is deemed to be critical to subsequent technological change.[52] It is measured as the number of citations a patent receives from future patents.[53] Generality refers to the technological breadth of a technology's impact on subsequent innovation. It is measured using the Herfindahl-Hirschman Index of the IPC codes of patent's forward citations. In the present investigation I compare a randomly drawn sample of patents developed by US firms, universities, and government research agencies to determine whether these dimensions reliably vary based on organization-type.

To preview the results, I find that patents assigned to universities are more important than those assigned to firms. That is, university patents are, on average and after controlling for other variables, cited more often than corporate ones. This finding is consistent with those of other scholars (Bacchiocchi and Montobbio 2009; Trajtenberg et al. 1997). I also find that patents assigned to universities and government research agencies are significantly more general than those assigned to firms. In other words, university and government patents affect subsequent technological change in a broader range of technological sectors than corporate patents. While theoretical arguments have been offered supporting the contention that universities and governments may have a

[52] In keeping with the terminological approach most commonly taken in the literature (see, for example, Bacchiocchi and Monobbio 2009: 170l; Moser and Nicholas 2006: 389; or Trajtenberg 2001: 364), the term "importance" is defined very narrowly to refer to the degree to which a given patent has been critical to subsequent (patented) technological change. Other scholars (Lanjouw and Schankerman 2004; Sampat et al. 2003) have chosen to characterize a patent's accumulated citations as a metric of "quality." While this a perfectly reasonable characterization, I prefer to use the term "importance" because it connotes the impact of the patent on *subsequent* technological change rather than describing an intrinsic feature of the patent of concern.

[53] Patent applicants are required to list all patented technologies deemed relevant to the invention underlying the application within the "prior art" section of their application documents. For a given patent, forward citations refer to the citations that a patent has received from future patents. Patents that receive a high number of forward citations can thus be said to have been important to the development of a large number of innovations.

comparative advantage vis-à-vis firms in developing general technologies, to my knowledge this is the first large sample empirical investigation of these claims. Finally, I define a subset of patents that are both highly and broadly cited. I find that both universities and government research agencies are significantly more likely to develop these high impact innovations than are firms. The empirical finding that universities and government research agencies are more likely than firms to produce highly and widely cited patents is novel. These findings are robust to model selection, the introduction to control variables, sample used, and the utilization of an alternative proxy for generality.

This chapter is motivated by the well-documented relationships between the importance and generality of patented innovations and economic outcomes. The remainder of this section briefly describes these relationships.

To justify the study of the relative technological importance of patents developed by different organization types one only need consider the extent of heterogeneity in patent importance and the positive economic and technological correlates of importance. The abundance of patents issued for trivial or incremental inventions is well documented.[54] This practice may be becoming more common (OECD Science, Technology and Industry Scoreboard 2011; Schmid and Wang 2016). In contest, other patented innovations have been shown to drive technological progress for years or decades (Feldman and Yoon 2011). The observed variation in the importance of patented innovations is correlated with metrics of a patent's technological and economic impact. For example, forward citations (this study's measure of importance) have been shown to correlate with expert perception

[54] The Electronic Frontier Foundation's "Stupid Patent of the Month" (https://www.eff.org/issues/stupid-patent-month) column offers incisive and amusing commentary on this trend.

regarding the technological contribution of a given patent (Albert et al. 1991). Forward citations have also been shown to relate positively to the market value of a patent (Chen and Chang 2010; Lanjouw and Schankerman 2004; Odasso et al. 2015). Thus scholars concerned with the identification of the determinants of radical technological change or the process of translating invention into economic outcomes should be interested in determining whether certain types of organizations tend to disproportionality develop highly cited patents.

The study of variation in the generality of innovations is motivated by the role that technological generality is thought to play in driving widespread technological advancement and economic growth. The general-purpose technology (GPT) literature is the primary literature describing the relationship between the generality of a technology and its effect on subsequent technological innovation and growth. This literature describes the process of technological innovation as one that occurs in waves (Youtie et al. 2008: 316).[55] According to the GPT framework, a wave of innovation is initiated when a GPT emerges and instigates a multi-sector surge of downstream innovation. Bresnahan and Trajtenberg (1995: 83) describe the catalytic role of GPTs on widespread technological change stating, "Whole eras of technical progress and economic growth appear to be driven by a few "General Purpose Technologies' (GPT's)."

Indeed, it is this purported contribution to accelerating widespread technological change that explains GPTs proposed role in driving economic growth. Bresnahan and

[55] Rather than waves, Bresnahan and Trajtenberg (1995) describe the relationship between GPTs and their successor technologies using the analogy of a family tree. Within such a treelike diagram, GPTs are located at the top of the structure, their spawned technologies radiating downward and outward. The essential feature in both analogies is the role of GPTs in *initiating* future technological change.

Trajtenberg (1995) argue that because GPTs act as “prime movers” for investment in complimentary innovations, they play an oversized role in determining economic growth rates (Bresnahan and Trajtenberg 1995: 84). While scholars differ in terms of the proposed model characteristics, many other studies have come to a similar conclusion regarding the centrality of GPTs to determining growth trajectories (Aghion and Howitt 1998; Helpman and Trajtenberg 1994; Helpman and Trajtenberg 1996).

Besides scholarly relevance, the study of organization-specific variation in the impact of innovative outputs has significant policy relevance. All of the organization types examined here depend, to some degree, on public resources. Local and national governments subsidize ostensibly innovative firms in the form of, *inter alia*, direct investment inducements, research and development tax credits, and tax deferments. Government research labs are completely dependent on public funding. Universities depend on grants, subsidies, and preferential tax status. The justification of directing public resources to these organizations is often based on the expectation that the impact of a funded innovation will extend beyond those resources initial destinations. That is, government spending on innovation is partially justified based on the expectation that funded innovations will spawn future innovation. Thus assuming policy makers seek correspondence between the stated objectives of their policies and policy outcomes, the efficacy with which distinct organization types spawn subsequent innovation is of direct relevance.

The remainder of this chapter is organized as follows. Section 2 reviews existing scholarship on the character of innovations produced by universities and government research agencies. From this literature a series of hypotheses regarding the character of university, government, and firm patents are extracted. Section 3 describes the data, measurement, and modeling strategy that are used to test these hypotheses. In Section 4, I present the results. Section 5 concludes.

5.2 Literature and Hypotheses

In the analysis to follow, I test six hypotheses. These hypotheses are derived from the existing theoretical and empirical literature on the comparative advantages of the three organization types considered here. The existing literature predicts that patents developed by universities and governments will be both more important and more general than those developed by firms. The rationale for these predictions is elaborated below.

5.2.1 University Patents

A wealth of theoretical and empirical scholarship contends that university-developed patents will, on average, differ from those assigned to firms. In regards to the characteristics under consideration here, patents developed by universities are argued to be particularly instrumental to subsequent technological progress and wide reaching in their technological influence. In the parlance of patent citation analysis, university-developed patents, when compared to those developed by firms, are argued to be important (highly cited) and general (draw their forward citations from a diverse set of technology classes).

Early theoretical support for these claims traces to the work of Richard Nelson (1959). While his focus is on explaining why the private sector will tend to supply basic research at a level below the social optimum, his reasoning can be applied to the development of patented inventions. Because innovation is cumulative, patents for which the underlying research is situated towards the basic end of the basic-applied research spectrum have the potential to be more important to subsequent innovation and spawn innovation in a wide range of technological sectors.

Nelson’s reasoning uses the marginal analysis that is characteristic of welfare economics.[56] He begins by observing that the returns to basic research will be widely diffused across applications, space, and time. It is thus unlikely that any given firm will be able to fully appropriate the social returns to an investment in basic research. Universities, in contrast to firms, are not purely profit-driven. Consequently, the appropriation problem faced by universities is less severe than for firms. Thus, according to Nelson, the comparative advantage of universities “lies in basic research” (Nelson 1959: 306).

Nelson goes on to argue that universities’ comparative advantage in the conduct of basic research is extended by two additional factors: patent law and the short time horizons used by firms. Patent law exacerbates the appropriation problem associated with the returns to basic research. The output of basic research, in that is consists largely of “natural 'laws' and facts,” is unlikely to be patentable (Nelson 1959: 302). Firms, precluded from using

[56] The net effect of the difficulties associated with appropriating the returns to basic research is to decrease investment in basic research by decreasing the expected revenue associated with such projects. Nelson’s framework assumes that, “A rationally planned inventive effort will be undertaken only if the expected revenue of the invention exceeds the economic exceeds the expected cost” (Nelson 1959: 300). Holding other factors constant, a decrease in expected revenue results in this profitability criterion holding for fewer projects.

the predominant mechanism for monetizing the outcome of their research, will tend to forego investment in basic research. Nelson also argues that firms will prefer applied research to basic research due to the long lead times associated with making fundamental scientific discoveries. Nelson explains that, "firms much concerned with short-run survival, little concerned with profits many years from now" will use higher time discount rates for basic research investments than are socially optimal (Nelson 1959 304).

More recently, Rosell and Agrawal (2009) have provided an additional explanation for universities' proposed comparative advantage in the development of general technologies. The authors explain that firms face pressure to narrow the diversity of the prior art used and cited in their patent documents, due to what Heller (1998) deems the anti-commons. That is, firms will conduct research and draft their patent applications with an eye towards minimizing exposure to the myriad, possibly overlapping, claims of other patents. Universities, in contrast, are partially insulated from the tragedy of the anti-commons due a legal exception that allows for patent infringement in cases of experimental use. Besides the experimental use exception, Rosell and Agrawal explain that university researchers will, relative to firms, select their research projects and prior art based on scientific merit. By selecting research based on scientific merit, and only considering patenting after the fact, university researchers avoid the *ex-ante* narrowing of scientific scope associated with the anti-commons.

In the US, Universities' comparative advantage in the production of basic knowledge has also been linked to the interaction between the federal government and university research. The large-scale insertion of the state into the American academy owes primarily to the military-university nexus established during World War II. Rosenberg and

Nelson cite the contribution of American academic researchers to the war effort as critical to determining the character of university-government relations in the post-war period. Buttressed by unprecedented public support and awareness of the utility of scientific research, Vannevar Bush's seminal document, *Science, the Endless Frontier*, advocated for the continuation of substantial government support for university research following 1945 (Bush 1945). Bush's advocacy, large-scale public support, and the highly visible demonstration of the practical utility of R&D expenditure, led to a Cold War university R&D funding structure centered around government funding (Rosenberg and Nelson 1994). During the Cold War, federal dollar contributions represented from 63% to 71% of total academic R&D spending. Increased federal funding did not merely shift R&D resources between sources, but resulted in a significant increase in research funding in real terms.

The post WWII surge in federal funding of university R&D affected the nature of university research. In the postwar era, strong industry-university ties were dominated by strong government-university ties, which shifted research priorities towards defense and health related research. For example, in the immediate postwar era, research focused on government priority technology areas such as digital computing (Project Whirlwind via the Office of Naval Research), numerically controlled machining (Air Force), and biotechnology. Besides shifting research towards prioritized federal projects, the focus on industry-led applied research that characterized the American system prior to WWII, was replaced by a "major shift in the nature of university research towards the basic end of the spectrum" (Rosenberg and Nelson 1994. p. 335). Illustrative of this pivot towards basic sciences in the 1950 was the establishment of the National Science Foundation (charged with funding basic research), the surge in Nobel prizes received by US citizens (US born and naturalized) in the 1930s and 1940s, and assentation of American universities to the status of global leaders in terms of scientific output.[57]

Finally, universities' purported relative advantage in developing GPTs is given additional theoretical support from the markets for technology framework (Bresnahan and Gambardella 1998). This framework contends that for special-purpose innovations, vertical integration is optimal while for general-purpose innovations the separation of upstream and downstream processes (i.e., disintegration) is preferred. Within this framework, universities are particularly well positioned to specialize in GPTs because they tend not to control downstream assets and thus will not be burdened by disintegration costs (Barirani et al. 2017). Firms, in contrast, will tend to be more vertically integrated and thus relatively well-positioned to take advantage of special purpose innovations.

Empirical evidence generally supports the contention that university patents are particularly likely to be cited by subsequent patents and that these citations will tend to come from a wide range of technology groups. Using similar proxies to those used here, Trajtenberg et al. (1997) find that compared to a control samples of corporate patents, university patents were, on average, more highly-cited and more general. While they do not look at generality, Bacchiocchi and Montobbio (2009) also find that university patents receive a higher number of citations. The authors also find that university patents are more likely to have received at least one citation. These results to not appear to depend on

[57] While the NSF was initially charged with a mission of advancing basic science, the 1968 reauthorization (Public Law 90-407) allowed the organization to fund applied and social science research.

jurisdiction; Trajtenberg et al.'s finding uses USPTO patents while Bacchiocchi and Montobbio (2009) use data from the European Patent Office.

Finally, it is important to consider the policy context in which universities operate. The Bayh Dole Act of 1980 allows universities ownership over intellectual property developed using federal spending. The purpose of the Act was to increase the commercial returns to federal R&D spending by encouraging universities to patent and license their discoveries. In this regard the Act was highly successful. The number of patents granted to universities doubled between 1979 and 1984 (Nelson 2001). Further, the number of universities with technology transfer or licensing offices grew by a factor of eight from 1980 to 1990 (Nelson 2001). The legislation's success has led to emulation; similar laws have been passed in China, Japan, Brazil, Malaysia and South Africa.

The primary relevance of the legislation to this dissertation relates to its potential affect in discouraging universities from conducting basic research. The logic behind this concern is as follows. The Bayh Dole Act increases universities' capacity to commercialize research. A higher proportion of research that is ripe for commercialization is applied (rather than basic). Thus, it is possible that universities will shift their research portfolios towards the applied end of the basic-applied spectrum in order to reap commercial returns.

However, empirical research suggests that this fear has not born out. Rafferty (2008) examines R&D data and is not able to attribute any increase in the basicness of R&D to the Bayh Dole Act. Other researchers (Mowery and Ziedonis 2000; Sampat et al.

2003) examine the effect of the legislation on patent data and find no significant change in patent quality or patent generality associated with the Act.[58]

Considering the theoretical arguments summarized above and the observation that university patents, from various jurisdictions, tend to be more highly-cited and general than corporate patents, it is possible to formulate the following testable claims.

Hypothesis 1: University patents will receive more citations than otherwise comparable corporate patents

Hypothesis 2: University patents will be more general than otherwise comparable corporate patents

5.2.2 Government Patents

The literature on the character of patents produced by government agencies is less well developed than that focusing on universities. As discussed in chapter 4, Vernon Ruttan provides the theoretical framework from which this study's hypotheses regarding government patents are derived. Ruttan (2001; 2006a; 2006b) argues that governments have been responsible for the development of a disproportionately large proportion of general-purpose technologies (GPTs). In making this claim, Ruttan traces the historical process by which important GPTs—certain early mass production processes, nuclear

[58] While an early study by Henderson, Jaffe, and Trajtenberg (1995) found a post-Bayh Dole decline in patent quality, Sampat et al. (2003) examine a longer period of forward citations and find that the observed decline in citations could be explained by a change in intertemporal citation patterns rather than a net reduction in citations received.

power, semiconductors, the Internet, and others—were developed. In each case, Ruttan finds that the US government played an important role not merely in funding a given technology's underlying basic research, but in the development of the technology itself. According to Ruttan, the outsized role of the government in the development of these technologies does not owe to mere historical accident or the government's ability to correctly select emerging GPTs. Rather, the government has played an important role in the development of GPTs because GPTs are characterized by two traits that deter private investment.

First, the returns to GPTs are highly dispersed across industries making their capture by a single firm unlikely. If firms are unlikely to appropriate the full returns to their investment, private investment will likely be below what is socially desirable. In such cases, the successful introduction of a GPT may depend on government intervention. Second, Ruttan argues that the long development cycles typical of GPTs often exceed the time horizons used by firms. Ruttan notes that the development of GPTs often takes decades and doubts that firms will have the "patient capital" necessary to make such long-term investments (Ruttan 2006b: 177). In essence, the high relative generality of government innovations owes to the government's comparative advantage vis-à-vis firms in providing public goods and making long-term investments.

A careful reader will have noticed that the reasoning underlying both of Ruttan's claims is analogous to that offered by Nelson (1959) and Rosell and Agrawal (2009). As described in chapter 4 of this dissertation, Ruttan's claim regarding the appropriation problem associated with GPT parallels the reasoning used by Nelson to describe the market failure associated with basic research. Second, Ruttan's claim regarding the role of time horizons is similar to Rosell and Agrawal's claim regarding the discount rates used by firms. Ruttan's contribution is to apply these traits to government funded GPTs and describe their impact on the historical role played by the government in their development.

The empirical literature on government-assigned patents is scant. Bacchiocchi and Montobbio (2009) find that patents assigned to government agencies accumulate more citations than a control group of corporate patents. While Drivas and Economidou (2013) do not look at government-assigned patents, they find circumstantial support for the large sample validity for the claims of Ruttan. In particular, the authors use USPTO data to find that patents developed using government funding were, on average, more basic that those that did not receive public support. Finally, in chapter 4 I find that in contrast to the expectation of prevailing theory, military patents diffuse at a rate that is not statistically disguisable from otherwise similar non-military patents. That is, despite the significant barriers to diffusion—export controls, the classification system, a static ecosystem of firms—that exist within the military technology innovation system, military technology patents are cited by other patents at a rate that is comparable to civilian technologies. I content that this counterintuitive finding might be driven by the logic proposed by Ruttan. That is, because the government often funds military technologies, these technologies might be disproportionately general. This generality effect may counteract the effect of the barriers that segregate the military innovation system from the civilian one. This proposed explanatory mechanism, however, is left untested. Indeed, I do not know of any previous studies that have compared the generality of government-assigned patent to those developed by other types of assignees.

Based on Ruttan's argument and the, admittedly scant empirical evidence, I extract the following testable claims regarding government patents.

Hypothesis 3: Government patents will receive more citations than otherwise comparable corporate patents

Hypothesis 4: Government patents will be more general than otherwise comparable corporate patents

5.2.3 Highly and Widely Cited Patents

The preceding discussion can be used to generate two final hypotheses regarding patents that are both highly *and* widely cited. If universities and governments are argued to have a comparative advantage in the development of important and general patents, these types of organizations may also be more likely to produce individual patents characterized by both high importance and high generality.[59] To my knowledge, these claims have yet to be tested empirically.

Hypothesis 5: Universities will be more likely to develop individual patents that are both highly cited and widely cited

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[59] While on first blush it may appear that if hypotheses 1-4 are supported by the evidence then hypotheses 5-6 will follow as a matter of deduction. If this were the case, including hypotheses 5-6 would be redundant. However, because hypotheses 1-4 make *probabilistic* claims regarding the innovative output of different organization types, it is not possible to apply the logic of transitivity. For example, hypotheses 5-6 make claims regarding a very small subset of innovations. In the empirical context considered here only 0.8% (132 of the 14,860 patents) of the sample are classified as highly and widely cited. It is thus possible that on average a given organization type will have patents that are more important and general than those of another organization type, while not developing a significantly higher number of the small subset of highly and widely cited patents.

Hypothesis 6: Governments will be more likely to develop individual patents that are both highly cited and widely cited

5.3 Data, Measurement, and Modeling Strategy

5.3.1 Data

This chapter aims to determine whether the innovations developed by different types of organizations—firms, universities, and government research agencies—vary in regards to their importance and generality. Towards this end, I compile a novel dataset of patents assigned to highly innovative representatives from each organization type over the period of 2006 to 2010. Table 13 provides the summary statistics and source for each of the variables used in the analyses to follow.

The dataset draws from two complementary data sources: the Derwent Innovation Index (DII) and the EPO Worldwide Patent Statistical Database (PATSTAT). The DII was used to source all of the data regarding individual patent characteristics. PATSTAT was queried to attain information on the characteristics of each patent's forward citations.

To create the dataset, I begin with a list of highly innovative assignees for each organization type.[60] All of the patents assigned to these organizations from 2006 to 2010 were collected and assigned to a bin based on whether the assignee was a firm, university, or government research agency. From each bin, I draw a random sample of 5,000 patents.

[60] The data appendix contains a comprehensive list of the assignees and a detailed description of the sampling strategy employed here. The author cleaned the data using Vantage Point (www.thevantagepoint.com), a text mining software.

After removing patents with missing information, those not listed in PATSTAT, and duplicate entries, I am left with a final data set comprised of 14,731 patents. Of these 4,990 (33.87% of the total) are corporate, 4,815 (32.69%) are university, and 4,926 (33.44%) are government.

Table 12 Descriptive Statistics, full sample

Descriptive Statistics, full sample

Variable	Obs.	Mean	Std. dev.	Min.	Max	Source
Dependent Variable						
Forward Citations	14,731	1.245	2.99	0	71	PATSTAT
Generality Index	5,504	0.084	0.189	0	0.882	PATSTAT [a]
Generality 2 (unique IPC codes)	5,504	1.274	0.77	1	16	PATSTAT
Highly cited and Highly General [b]	132 (0.89% of sample)					PATSTAT
Independent Variables						
University Assignee [b]	4,815 (32.7% of sample)					Derwent
Government Assignee [b]	4,926 (33.4% of sample)					Derwent
Corporate Assignee [b]	4,990 (33.9% of sample)					Derwent
Control Variables						
No. of Assignees	14,731	2.297	2.105	1	28	Derwent
Tech. Breadth	14,731	2.621	1.538	1	16	Derwent
Jurisdictional Coverage	14,731	3.052	3.586	1	62	Derwent

[a] Authors' calculations based on PATSTAT data, [b] Category variable, "Obs." refers the representation of the category in question.

5.3.2 Dependent Variables

Importance: The first dependent variable considered here is technological importance. I operationalize technological importance using patent citation data. During the patent application process, patent applicants and the patent examiner are required to cite previous patents that reveal the state of the art for the innovation under consideration. The patents included in this prior art section represent the focal patent's antecedent technologies or the technologies, and their embedded knowledge, on which the underlying innovation relies. The number of times that a patent appears as prior art—its "forward citations" count—is thus a direct measure of the extent to which a patent has been deemed important to subsequent innovation.

The practical import of forward citations is that it measures a patent's technological impact. Patents that are not cited by subsequent patents are "a technological dead end" (Jaffe and Rassenfosse 2017: 2). In contrast, highly cited patents have been deemed by inventors, or patent examiners, as important to subsequent technological change.

For each patent in the dataset, I search five years of subsequent patenting in PATSTAT—from the focal patent's date of publication—for forward citations. The number of times a patent is cited within this five-year window constitutes its measure of technological importance. Operationalization of importance using forward citations counts is validated by empirical evidence showing that forward citation correlate strongly to the opinions of knowledgeable peers about the technological significance of a given patent (Albert et al. 1991) and the patent's market value (Odasso et al. 2015). Similarly, Czarnitzki and colleagues (2011: 131) find that patents described by an employee of the

World Intellectual Property Organization (WIPO) to have "only marginally satisfy the "non-obviousness' criterion" receive fewer citations that those in a control group. Finally, the validity of the use of forward citations as a measure of the importance of a given patent is enhanced by considering a single very highly cited patent. Azagra-Caro et al. (2017) identify Cohen and Boyer's process for creating molecular chimeras as the most highly cited university patent over the period 1990-2007. This patent (US4237224) has been found to have had an enormous role in stimulating subsequent technological change (Feldman and Yoon 2011).

Generality: A perennial problem in the study of general-purpose technologies is what might be termed the classification problem. That is, with the exception of a handful of clear-cut cases such as electricity and computers, it is often unclear which technologies should be included within the GPT category.[61] One way to circumvent this issue is to avoid discrete approaches to classification and assign a given innovation a non-discrete measure of its "generality." Using this approach, a given patent is assigned a generality "score" based on the extent to which its underlying intellectual property is broadly used by subsequent patents.

[61] Some scholars have even questioned the status of these apparently clear-cut GPTs. While Jovanovic and Rousseau (2005: 1182) cite electricity as one of the two "most important GPTs so far," Moser and Nicholas (2006) fail to find evidence that electricity patents were more general than a control group. The failure of scholars to agree on what constitutes a GPT suggests that continuous metrics of generality (such as those used here) may be preferable to a binary classification.

This is the approach taken here. In particular, I define generality as one minus the Herfindahl-Hirschman Index of the 4-digit primary IPC codes for a given patent's forward citations. More formally:

$$G_i = Generality = 1 - \sum_{j}^{n_i} S_{ij}^2$$

such that S_{ij} is the ratio of the forward citations received by patent *i* that belong to classification *j*. As the patents that cite a given patent come from an increasingly diverse set of IPC classifications, the generality index approaches one. In contrast, a patent that has accumulated all of its forward citations from a single IPC code will have generality index score of zero.

As an alternative measure of a patent's generality, I use the unique 4-digit IPC codes from a given patent's forward citations. Each patent is assigned at least one IPC based on the technology field in which the patented invention falls. Patents that are cited by patents from a large number of technology classes are more general than those that are cited by patents from a small number of subfields. Thus, the count of the unique 4-digit IPC codes that a patent draws its citations from is an alternative measure of the breadth of the patented technology.

Highly cited and highly general patents: In order to determine whether universities and governments are more likely to produce high-impact patents, I identify a subset of patents within the sample as being both highly cited and highly general. To define this subset of patents, I assign each patent in the sample to a quintile for both variables (forward citations and generality). Patents that are in the top quintile for *both* variables are assigned a value of 1.[62] Other patents are assigned a 0. Thus, the small subset of patents assigned a 1 (there were 132 in the sample) constitute patents that are amongst top twenty percent of the distribution for citations received *and* generality. Of the 132 highly and widely cited patents in the sample, 29 (22%) were produced by firms, 56 (42%) were produced by universities, and 47 (36%) were produced by government research agencies.

5.3.3 Independent Variable

Organization Type: The primary independent variable of interest is the organization type––firm, university, or government research agency—of a patent's assignee. In the analysis to follow, I set the reference group equal to patents assigned to firms. University patents are assigned a 1 and those assigned to government research agencies are assigned a 2.

5.3.4 Control Variables

For a research design such as this, variables that have been consistently found to correlate with the study's dependent variables should be added as controls (King et al. 1994). I select a set of patent-level control variables based on this criterion. First, I control for the number

[62] Because in this portion of the analysis, I are interested in very high performing patents, I limit the quintile calculations to patents that receive at least one forward citation. If I had included the zeros in the quintile calculations, the cutoff point would have been two forward citations due to the high number of patents that are never cited. The top quintile cut off point is five forward citations. The top quintile cutoff point for generality is 0.586.

of assignees on a patent. The technical or scientific complexity of an underlying invention is likely to correlate with the number of parties involved in the invention's development. Because a patent's importance and generality are also likely to correlate in relation to technical or scientific complexity, I add assignee counts to the models that follow.

To account for the technological breadth of the patented invention, I control for the number of Derwent Classification Codes that have been assigned to each patent. Patents assigned a large number of technology classes are likely to have greater technological coverage than those assigned a small number of subclasses (Harhoff et al. 2003). Because greater technological coverage is likely to be associated with differences in citation behavior, counts of technology classes are included in the regression models that follow.

Third, I add a control variable for the number of jurisdictions in which a patent has been filed. Sampat (2005) finds patents filed in multiple countries to be of higher quality than those filed in a single jurisdiction. Because patent quality is likely to correlate with both diffusibility and generality, a control for each patent's jurisdiction count is included. Finally, to control for inter-temporal variation, I include a set of patent application year dummy variables.

5.3.5 Models

To test the six hypotheses put forth in Section 2, three distinct dependent variables are used. These dependent variables require the use of three distinct modeling approaches. The dependent variable used to test hypotheses 1 and 2 is five-year forward citations. Forward citation data are counts (i.e., they are nonnegative and discrete) and thus suggest the use of the Poisson family of models (Hoffman 2004). Because in the sample these data are overdispersed (the mean = 1.24 is higher than the variance = 2.99) a negative binomial regression model is estimated. The alpha parameters reported in Table II confirm negative binomial regression to be preferable to Poisson models here. Consistent with the literature, the vast majority (62.84%) of patents in the sample receive zero citations. To verify that "excess zeros" do not drive the results I also fit a zero-inflated negative binomial (ZINB) regression model.[63] In consideration of space, the results of the ZINB are presented in the appendix. The curious reader will find that the results mirror those presented in Table II.

The dependent variable used to test hypotheses 3 and 4 is a patent's generality index score. The generality index assumes continuous values between 0 and 1. This characteristic makes linear regression inappropriate. While values of zero (i.e., when all of a patent's forward citations come from a single IPC class) are common in the data, the upper bound is never reached in the generality index. Because zero values are possible, beta regression is inappropriate. Under these conditions, Papke and Wooldridge (1996) recommend the use of fractional regression. I thus fit the generality index using a fractional probit regression with robust standard errors to correct for heteroskedasticity. Because calculating the generality index requires a patent to have been cited by subsequent patents, this model is estimated using the subset of 5,504 patents that received at least one forward citation within five years of their date of publication.

[63] "Excess zeros" refer to the zeros that exceed the distributional assumptions of the count distribution (in this case a negative binomial distribution).

I test the robustness of the effect of organization type on generality (i.e., hypotheses 3 and 4) in two ways. First, I estimate the fractional regression on a sub-sample of patents that received more than one forward citation. Because a fairly large proportion (14.78%) of the patents that receive at least one citation, receive only a single citation and a patent with a single citation will, by construction, have a zero generality index score, fitting the model to this alternative sample seeks to ensure that the observed relationship is not driven by these zero values. Second, I run the model using an alternative measure of generality: the number of unique IPC codes from a patent's forward citations. Unique IPC codes are counts, yet are not overdispersed, so a Poisson model is fit. Again, the regression tables for the robustness checks are provided in the appendix. The results strongly mirror those presented in Table 15, suggesting the results to be robust to sample utilized and measure of generality.

Finally, the dependent variable used to test hypotheses 5 and 6 is a binary variable. Patents that are both highly and widely cited are assigned a value of one; other patents are assigned a zero. Thus, I use a probit model to test hypotheses 5 and 6. In all of the models presented in Section 4 and the appendix, Huber-White robust standard errors are used to correct for heteroskedasticity.

5.4 Results

Table 14 presents the results of the tests for importance. The analysis suggests that patents assigned to universities are cited more than those assigned to firms. This relationship is robust to the inclusion of controls (see model 2) and to the alternative (ZINB) specification (see Table A1 in the appendix). This result supports that of Trajtenberg, Henderson and Jaffe (1997) who use a different patent data source and time period to find that university patents receive more citations that corporate ones.

Whereas the postulate that university patents will be more highly cited than corporate patents (Hypothesis 1) is supported by the data, I fail to find a similar effect for patents assigned to government research agencies. That is, I find no statistically significant difference in the number of citations accumulated by patents with government assignees.

Table 13 Negative binomial regression of importance (forward citations), 2006-2010

Negative Binomial Regression of Importance (forward citations), 2006-2010		
	(1)	(2)
University Assignee	0.285	0.208
	(5.76)***	(4.15)***
Government Assignee	0.093	0.014
	(1.84)	(0.28)
No. of Assignees		0.076
		(8.16)***
Tech. Breadth		0.032
		(2.63)**
Jurisdictional Coverage		0.028
		(5.13)***
Year Dummies	YES	YES
Constant	0.276	-0.039
	(4.45)	(-0.55)
Wald χ^2	251.23***	380.83***
Alpha	3.60	3.50
Log pseudolikelihood	-20515	-20435
Observations	14,731	14,731

All coefficients are unstandardized. Robust z statistics parentheses, standard errors are clustered at the basic country level, * p<0.05, ** p<0.01, *** p<0.001

Table III provides the results for the tests of hypotheses 3 and 4. The analyses indicate that university and government patents are more general than those assigned to firms. Comparing the coefficients for University Assignee (0.311) and Government Assignee (0.252) to the standard deviation for the generality index (0.189) suggests that the organization effect size is large in magnitude. Tables 19 and 20 provided in the appendix indicate that this relationship holds in the restrictive sample condition and using an alternative proxy for generality. In sum, hypotheses 3 and 4 are strongly supported by the evidence provided here; university and government patents are significantly more general than their corporate counterparts.

Table 14 Fractional probit regression of generality index, 2006-2010, full sample

Fractional Probit Regression of Generality Index, 2006-2010, full sample		
	(1)	(2)
University Assignee	0.334	0.311
	(7.88)***	(7.21)***
Government Assignee	0.291	0.252
	(6.69)***	(5.70)***
No. of Assignees		0.029
		(4.23)***
Tech. Breadth		0.017
		(1.70)
Jurisdictional Coverage		-0.000
		(-0.23)
Year Dummies	YES	YES
Constant	-1.613	-1.723
	(-29.54)***	(-27.50)***
Log pseudolikelihood	-1548	-1543
LR χ^2 (6,9)	217.68***	238.73***
Observations	5,504	5,504

All coefficients are unstandardized. Robust z statistics parentheses, standard errors are clustered at the basic country level, * $p<0.05$, ** $p<0.01$, *** $p<0.001$

Finally, Table 16 indicates that universities and governments are more likely to produce individual patents that are both highly cited and highly general. That is, I find evidence in support of hypotheses 5 and 6. Universities are particularly adept at developing such patents; 42% of all of the patents that were in the top quintile for citations received and generality were assigned to universities.

Table 17 summarizes the six hypotheses tests here. In general, the study supports the theoretical scholarship predicting that universities and government research agencies have a comparative advantage vis-à-vis firms in developing technologies with deep and wide impact.

Table 15 Probit regression of highly cited widely cited dummy, 2006-2010

Probit Regression of Highly cited Widely Cited dummy, 2006-2010		
	(1)	(2)
University Assignee	0.354	0.334
	(4.28)***	(4.00)
Government Assignee	0.296	0.267
	(3.62)***	(3.26)***
No. of Assignees		0.047
		(4.02)***
Tech. Breadth		-0.001
		(-0.08)
Jurisdictional Coverage		0.010
		(1.53)
Year Dummies	YES	YES
Constant	-3.128	-3.293
	(-17.64)	(-16.87)***
Log pseudolikelihood	-721	-712
LR χ^2 (6,9)	82.04***	101.85***
Observations	14,731	14,731

All coefficients are unstandardized. Robust z statistics parentheses, standard errors are clustered at the basic country level, * p<0.05, ** p<0.01, *** p<0.001

Table 16 Results summary, hypothesis tests

Table V.
Results Summary, Hypothesis Tests

	Supported?
Hypothesis 1: Importance, University > Corporate	YES
Hypothesis 2: Generality, University > Corporate	NO
Hypothesis 3: Importance, Government > Corporate	YES
Hypothesis 4: Generality, Government > Corporate	YES
Hypothesis 5: High Impact, University > Corporate	YES
Hypothesis 6: High Impact, Government > Corporate	YES

5.5 Conclusion

Do technological innovations developed by different types of organization vary with regards to their effect on subsequent technological progress? Here I have shown that they do and that organization effects in the United States are statistically robust and large in magnitude. Specifically, university patents are more general than corporate ones. Government patents are more highly cited and more general than corporate patents. Both university and government patents are more likely to belong to a small subset of patents that are both highly cited and highly general. While a detailed description of the policy implications of these results is beyond the scope of this chapter, it is worth briefly identifying the policy decisions with which these results may interact.

While there is large between and within group variation, each of the organization types examined here receives considerable public resources. In almost all countries, universities are tax exempt and receive large government grants. These outlays seek not only to increase access to higher education but also to advance scientific research and promote economic development through the promotion of technological innovation (Schmid et al. 2017; Youtie and Shapira 2008). The results provide circumstantial evidence that such public outlays to universities may be warranted. That is, the finding that university patents have a particularly deep and wide impact on subsequent technological change suggests that policies that attempt to use universities as engines for advancing technological innovation may hold promise.

Similarly, the findings support the policy recommendations made by scholars such as Ruttan to publically fund basic research via government research labs. Ruttan (2001;

2006a; 2006b) asserts that governments, primarily through funding, are disproportionally responsible for the development of general technologies. This claim is based on his contention that governments – due to their lack of profit motive and long time horizons – have a comparative advantage in the development of technologies whose returns are difficult to appropriate and whose viability requires the use of a low time discount factor. The finding that governments in fact produce technologies that are more general than those produced by firms supports Ruttan's reasoning and his recommendation to publically fund basic research.

However, it is important to recognize that the research design does not allow us to make judgments about the counterfactual. It is possible that in the absence of public funding, firms would have developed a higher proportion of general patents. That is, further study is necessary to determine whether universities or government research labs crowd-out certain types of private innovation. Nevertheless, the findings support the notion that universities and governments have a comparative advantage in the development of high impact technologies and that increased funding of such agencies may drive future technological innovation. Chapter 6, section 6.3.3, provides a description of a research design – modeled on that employed here – that could be used to empirically test the relative tendency of different organization types to produce GPTs.

5.6 Technical Details – Sampling Strategy

The dataset utilized in the proceeding analyses constitutes a concatenation of three purpose-built patent datasets: one comprised of government-assigned patents, one comprised of university-assigned patents, and one comprised of firm-assigned patents. The source data used to create these datasets comes from two complementary sources: the Derwent Innovation Index (DII) and the EPO Worldwide Patent Statistical Database (PATSTAT). The DII was used to source all of the data regarding individual patent characteristics. For each patent, PATSTAT was queried to attain information on the characteristics of each patent's forward citations.

For each organization type, I gather a random sample of five thousand patents that were assigned to the most innovative US organizations within that organization type. In order to determine the most innovative organizations within each organization type, the following criteria were used.

Government Patents

The twelve government research agencies included in the analysis constitute all of the US agencies listed in the government agencies sections of the annual IEEE Spectrum Patent Power lists from 2010-2015. Over the period of analysis used in the preceding analyses, these agencies were listed as assignees on 5,593 patents. From these 5,593 patents, a random sample of 5,000 were drawn to constitute the government patents sub-sample of the final sample.

The government assignees used in the analysis are: U.S. Air Force, National Aeronautics and Space Administration, U.S. Department of Energy, U.S. Department of Agriculture, U.S. Department of Commerce, U.S. Department of Veterans Affairs, National Security Agency / Central Security Service, U.S. Navy, U.S. Postal Service, U.S. Army, U.S. Department of Health and Human Services, and the U.S. Environmental Protection Agency.

University Patents

The 40 universities included in the analysis constitute all of the US universities listed in the university section of the annual IEEE Spectrum Annual Patent Power lists from 2010-2015. Over the 2006-2010 period of analysis, these universities were listed as assignees on 22,047 patents. A random sample of 5,000 were drawn to constitute the university patents sub-sample of the final sample.

The university assignees used in the analysis are: California Institute of Technology, University of Colorado, Cornell University, Georgia Institute of Technology, Harvard University, Indiana University, Iowa State University of Science and Technology, Massachusetts Institute of Technology, Northwestern University, The Ohio State University, University of California, Rice University, Rensselaer, Stanford University, University of Texas, Tufts University, University of Massachusetts, University of Maryland, University of Illinois, University of Iowa, University of Washington, University of Michigan, University of Pennsylvania, University of Southern California, University of Utah, Clemson University, Carnegie Mellon University, Columbia University, University of Central Florida, Loma Linda University, University of Miami, North Carolina State University, New York University, State University of New York (SUNY), Oregon State

University, Purdue University, University of South Carolina, University of South Florida, University of Wisconsin, and Virginia Polytechnic Institute.

Corporate Patents

The 16 firms included in the analysis constitute all of the US firms that fell within the top ten patent owners from 2010-2015. The Intellectual Property Owners Association compiles the list of top patent owners.[64] Once duplicates are removed, 16 American firms remain.[65] Firms that have been acquired (Broadcom Corporation) are included in the analysis, as their patents still receive citations from subsequent patents. These 16 organizations are listed as assignee on over 100,000 patents during the period of analysis. A random sample of 5,000 of these patents was used here to constitute the corporate patents sub-sample of the final sample.

The firm assignees used in the analysis are: IBM, Microsoft, Intel, Hewlett-Packard, General Electric, Oracle, Cisco Systems, Honeywell, Xerox, AT&T, Broadcom, General Motors, Qualcomm, Google, Apple, and Ford.

[64] The IEEE Spectrum Annual Patent Power reports do not have a single category for firms. Instead the corporate entries are listed by sector (e.g., Chemicals, Computer Software, Electronics, etc). Thus, in order to select the most innovative firms, I use the annual list of the top US patent holders that is issued by the Intellectual Property Owners Association. The annual releases of these data were collected from https://www.ipo.org/index.php/publications/top-300-patent-owners/ (accessed January 5, 2017).

[65] This method of firm selection results in a sample comprised exclusively of large firms. Additional investigation into the characteristics of the innovative activity of small and medium sized firms is necessary to extend this study's findings to the private sector writ large.

The Final Sample

The final dataset utilized in the proceeding statistical analyses constitutes the concatenation of the three 5,000 patent samples. After removing patents with missing information, those absent from PATSTAT, and duplicates, I was left with a final data set comprised of 14,731 patents. Of these 4,990 (33.87% of the total) are corporate patents, 4,815 (32.69%) are university patents, and 4,926 (33.44%) are government patents.

5.7 Technical Details – Robustness Checks

Table 17 Zero-Inflated negative binomial regression of importance (forward citations), 2006-2010

Zero-Inflated Negative Binomial Regression of Importance (forward citations), 2006-2010		
	Logistic (1)	Negative Binomial (1)
University Assignee		0.304 (6.06)***
Government Assignee		0.222 (4.21)***
No. of Assignees	-0.796 (-2.52)*	0.025 (2.68)**
Tech. Breadth	-0.01 (-0.23)	0.016 (1.31)
Jurisdictional Coverage	-3.00 (-5.20)***	0.004 (0.86)
Year Dummies	YES	YES
Constant	3.686 (4.32)***	0.251 (3.38)**
Wald χ^2 (9)	187.47***	
Log pseudolikelihood		-20105
LN α		0.996***
Observations	14,731	14,731
All coefficients are unstandardized. Robust z statistics parentheses, * p<0.05, ** p<0.01, *** p<0.001		

Table 18 Fractional probit regression of generality Index, 2006-2010, restricted sample (two or more forward citations)

Fractional Probit Regression of Generality Index, 2006-2010, restricted sample (two or more forward citations)		
	(1)	(2)
University Assignee	0.338	0.316
	(7.26)***	(6.66)***
Government Assignee	0.329	0.293
	(6.94)***	(6.07)***
No. of Assignees		0.025
		(3.22)**
Tech. Breadth		0.174
		(1.58)
Jurisdictional Coverage		-0.001
		(-0.29)
Year Dummies	YES	YES
Constant	-1.363	-1.459
	(-22.95)***	(-21.57)***
Log pseudolikelihood	-1307	-1304
LR χ^2 (6,9)	182.35***	196.14***
Observations	3,316	3,316
All coefficients are unstandardized. Robust z statistics parentheses, standard errors are clustered at the basic country level, * p<0.05, ** p<0.01, *** p<0.001		

Table 19 Poisson regression of unique IPCs of forward citations, 2006-2010

Poisson Regression of Unique IPCs of forward citations, 2006-2010		
	(1)	(2)
University Assignee	0.137	0.130
	(6.72)***	(6.32)***
Government Assignee	0.113	0.098
	(5.41)***	(4.68)***
No. of Assignees		0.013
		(4.05)***
Tech. Breadth		0.002
		(0.36)
Jurisdictional Coverage		-0.001
		(-0.33)
Year Dummies	YES	YES
Constant	0.99	0.641
	(4.31)***	(2.37)*
Wald χ^2 (6, 9)	182.38***	195.48***
Log pseudolikelihood	-6664	-6661
Observations	5,504	5,504
All coefficients are unstandardized. Robust z statistics parentheses, standard errors are clustered at the basic country level, * p<0.05, ** p<0.01, *** p<0.001		

CHAPTER 6. CONTRIBUTIONS, EXTENSIONS, AND LIMITATIONS

This chapter considers the theoretical and empirical contributions of this dissertation in a larger context. While each chapter provides a summary the immediate scholarly context into which the chapter's findings fit, this section takes a step back to consider a broader swath of literature. I begin by placing the dissertation's theoretical and empirical contributions into the context of the overall military innovation literature. Second, I consider the implications of my results for the literature on the changing role of the university. Third, I summarize the dissertation's primary contributions to social science methodology. I then propose three extensions to the research conducted here and outline the means by which scholars might use the theory, methods, and metrics proposed here to answer pending research questions. This chapter concludes by elaborating an important limitation to the dissertation.

6.1 This Study's Contribution to the Assessment of Theory

6.1.1 Military Innovation Theory

The theories of military innovation considered in this dissertation treat the primary determinant, the external threat environment, very differently. In Posen's civilian-military relations model, external threats initiate the civilian review of military affairs that produces innovation. Rosen's intra-military theory of innovation treats external threats as a second-order concern. Other scholars ignore the role of threats completely.

The results presented in chapters 2 and 3 thus have direct consequences for the explanatory merit of each theory. A finding that states facing a high degree of external threat innovate at a higher rate than states facing lesser threats would strengthen theories emphasizing the role of the external security context in driving innovation. In contrast, a null result would provide indirect support for theories focusing on the internal composition of military bureaucracies. This section compares the results of chapters 2 and 3 of this dissertation – i.e., that threats appear to stimulate technological and organizational innovation within militaries – to the leading theories of military innovation in order to evaluate how each theory fares.

Of the primary theories of military innovation, Posen's civilian-military relations model makes the strongest claims regarding the catalytic role of the threat environment. Indeed, the causal sequence towards doctrinal innovation in Posen's empirical cases is often initiated by an increase in the likelihood of conflict.[66] He observes that, "states respond to potentially dangerous increases in the power of their putative adversaries" not merely by forming alliances and increasing the size of their military, but by "audit[ing] their military doctrines" (Posen 1984: 40).

[66] Posen, on occasion, underscores the contribution of individuals or mavericks in pushing through technological change. This argument has also been made by Murray (1996) who cites Dowdings role in transforming the RAF during WWII. In this case of military innovation, Murray emphasizes Dowdings' personal qualities such as vision and ability to reverse his position in light of evidence as being critical to the transformation of the British Airforce during the period. Murray also emphasizes the role of military culture, contrasting the German military's strong norm of honest evaluation with interwar Brittan's lack of self-appraisal. Specifically, he cites Archibald Montgomery-Massingberd's 1932 suppression of a report that was critical of British Army's performance during WWI. However, accounts of military change based on the individual actors or culture present measurement challenges when a large sample research design is employed.

Posen illustrates the process by examining historical cases. He observes that when the British civilian leadership perceived an increased likelihood of German bombing, they pressured the Royal Air Force to build a defensive fighter squadron. This increased scrutiny represents a kind of power balancing whereby the civilian sector seeks to ensure that military doctrine is “up to the task” of heightened security threats. In summary, according to Posen, the increased civilian scrutiny that drives innovation is initiated by changes in the threat environment. Put into the terminology employed in this dissertation, Posen hypothesizes that an increase in the external threat environment will, all else constant, increase a state’s propensity to innovate.

While Posen applies his theory of military innovation to the cases of interwar Germany, Brittan, and France, Avant (1993), Zisk (1993), and Kaufman (1994) apply the civilian-military relations model of military innovation outside of Posen’s original cases. Deborah Avant (1993) explains the variation in British and American adaptability to similar threats (Avant observes that Brittan was able to innovate during the Boer War, while the US during Vietnam War was not) as a function of the ability of the civilian sector to effectively intervene in military affairs.[67] Kimberly Zisk explains that civilian defense experts were critical in allowing the Soviet Union’s adaption in changes in US and NATO doctrine during the Cold War. Kaufman observes that the Brezhnev-era civilian Soviet leadership was able to force the military to abandon its support for an anti-ballistic missile defense and to sign the 1973 Anti-Ballistic Missile Treaty. Posen’s theory – along with its

[67] While Avant focuses on the manner in which the British and American political systems affected the ability of the civilian sector to deliver a single coherent message to the military, her emphasis on the role of civilians in driving military change explains her inclusion here.

extensions by Avant (1993), Zisk (1993), and Kaufman – are supported by the data and analysis presented in chapters 2 and 3.

Another theory supported by the evidence presented in chapters 2 and 3 is that of Taylor (2004; 2012, 2016). Taylor's model – creative insecurity – of overall national innovative productivity gives prominence to security threats. According to the author, "all else equal, countries for which external threats are relatively greater than domestic tensions should have higher national innovation rates than countries for which domestic tensions outweigh external threats" (Taylor 2012:117). While Taylor's focus is on overall (not military) rates of innovation, in a 2012 article he refers to the role of threat-induced technological innovation in increasing national defense capacity, stating, "external threats act to increase political support for technological change. Militaries can use technological change to build their indigenous defense capacity; civilians can use innovation to forge a more competitive export sector. New technology thereby allows states to better protect their borders and earn foreign exchange for strategic imports via higher value and more competitive exports" (Taylor 2012: 117).

While the theoretical implications are less direct, it is also illustrative to apply the finding that threats drive innovation to one of primary theoretical workhorses of international relations: structural realism. Keohane (1986) notes that classical realism posits three assumptions: that states are the primary actors in international relations, that states seek power and that states act rationally towards this end. Waltz's (1979) formulation maintains these assumptions, but attempts to shift the focus of analysis away from individual states in order to identify the characteristics of the system in which states operate. As in classical realism, states remain the primary actors in Waltz's theory. What matters inside this structure is the relative position of the units rather than the particular internal distinctions between them. The units of analysis, states, have the same goals (that is, they are functionally similar) and often emulate each other. In sum, Waltz theory assumes states to be functionally alike units acting in the same anarchic system to realize the same goals.[68]

The novel aspects of Waltz's realism primarily concern the nature of the international structure. Specifically, Waltz defines anarchy and self-help as the most important characteristics of the international structure. Anarchy refers to the lack of a supreme governing authority in the international realm and self-help refers to the assumption that states will act to protect or advance their own interests. The property of self-help can take either a strong or a weak form. In the weak form, states merely seek survival while in the strong form states aim to increase their position relative to other states. Waltz explains that self-help is a necessary characteristic of an anarchic system. From the assumptions of anarchy and self-help, emerge another of the structure's characteristics, the balance of power.

Waltz cites the appearance of continuity in state behavior as evidence of the existence of an underlying international structure. In particular, Waltz suggests that by observing states that have distinct forms of government behaving in a similar manner, one can deduce that the underlying motivation for action is found in the shared international structure. Describing the role of anarchy in creating continuity Waltz states, "The enduring

[68] While Waltz describes states as functionally similar, he does not completely discount states' ability to affect their standing in terms of their relative power position. States can take internal actions (such as investing in weaponry or technology) or external actions (such as forming alliances) that influence their position within the international structure.

anarchic character of international politics accounts for the striking sameness in the quality of international life through the millennia" (Keohane 1986: 53).

Just as Waltz uses the structure of the international system to explain continuity, he attributes changes in state behavior to changes in the system. The actions of a state will be determined by the structural conditions faced at a given time and the assumption of rationality. Thus, changes in the way that states behave are due to variations in the structural conditions they face rather than domestic heterogeneities.

The findings presented in chapters 2 and 3 offer indirect support for Waltz's structural realism. The observation that states increase military technology output in response to an increased threat condition can be interpreted as Waltzian internal balancing. While Waltz says relatively little about weapons development as a means of balancing, responding to threats by means if the mobilization of military resources supports the structural realist approach.

In contrast to Posen, Taylor, and Waltz, other scholars have subordinated the role of a state's threat environment in driving military change. In Rosen's intra-military explanation for innovation, external threats are treated as secondary to the organizational conditions of the military. In the author's words, "The overall picture of American military research and development in the period from 1930 to 1955 is one of technological innovation largely unaffected by the activities of potential enemies, a rather self-contained process in which actions and actors within the military establishment were the main determinants of innovation" (Rosen 1991: 250).[69] When considering the United States' development of intercontinental ballistic missiles (ICBM), Rosen explicitly discounts the role of external threats and theories of innovation based on civilian-military relations noting, "It was not a Soviet threat, or a civilian scientific intervention in the context of fixed technological possibilities that pushed the innovation of the ICBM, but a new and unforeseen technological innovation created by civilian physicists" (Rosen 1991: 248). This account – what may be deemed technology push – of military innovation is difficult to reconcile with the correlations observed in chapter 2. This does not preclude the possibilities that, on occasion, civilian technological change drives military technology change, but rather that structural factors play a larger role than they are afforded in Rosen's account.

Indeed, because organization theory and bureaucratic-politics approaches typically describe organizations as tending towards stasis or equilibrium, their capacity to explain innovation is somewhat limited. Change, is viewed as the exception, necessitated, on occasion, by exigent circumstances but resisted by the majority of individuals within the organization. Such organizations will pursue innovation in weaponry only when such technologies are not overly disruptive to the functioning of the organization. Thus, organization theory predicts that while incremental innovation is possible because it does

[69] While Rosen does contend that changes to the "international security environment" might spur innovation, his definition of the international security environment differs substantially from the notion of external threats considered here. Indeed, Rosen is explicit in omitting the actions of potential enemies from his definition of the international security environment, noting, "The international security environment is composed of those factors not under the control of either the United States military or the government of hostile powers but that constrain or create opportunities for the military" (Rosen 1991: 57).

not upset the status quo, innovation in weapons technology that require organizational transformation will tend to face strong resistance.

Matthew Evangelista (1998) provides another account of military innovation in which the causal contribution of threats is subordinated. In explaining innovation during the US-USSR arms race, Evangelista rejects the dichotomy of organizational versus structural explanations of weapons innovation. The explanatory utility of each theory, he contends, depends on the context to which it is applied. Specifically, internal-focused explanation more-closely fit the US cases examined by Evangelista. Weapons innovation in the USSR, in contrast, is argued to be primarily a function of the international system. For example, Evangelista contends that the Soviet development of tactical nuclear weapons was response to the US deployment of such weapons in Europe in 1952. Evangelista gives the example of the US/USSR weapons innovation gap as evidence contradicting theories of innovation military technology based solely on structural or external factors. He argues, that because the US and the USSR dedicate similarly large portions of output to R&D and face similar structural conditions, the observed disparity in weapons innovation must depend on variation in domestic conditions with each state.

In summary, when attempting to explain complex social phenomenon significant epistemological humility is warranted. Generally, I agree with the contention of Stephen Peter Rosen that, it is, “unlikely that explanations of innovation will have universal applicability” (Rosen 1991: 5). The theories of military innovation described above and in chapter 2 are not readily converted into a series of hypotheses that might be definitively tested using statistical analysis. To do so would be to denude the arguments of their nuance. Neither are many of the arguments’ central components (e.g., organizational characteristics, competition, or the influence of individuals) easy to quantify. Nevertheless, the discussion above demonstrates that these theories do differ significantly in their treatment of the international threat environment. Within models of military innovation based on intra-service or inter-service competition, threats alone are insufficient to drive innovation. In contrast, within the accounts offered by Posen and Dombrowski and Gholz (elaborated in chapter 2), foreign threats initiate a causal sequence leading to military innovation. In Posen's account, threats incite civilian scrutiny, which provokes otherwise change-resistant organizations to innovative. In Dombrowski and Gholz's model, foreign threats lead Congress to acquiesce to the continual lobbying by the military services for additional R&D funding. These funds, in turn, lead to technological innovation. Thus while the empirical analysis presented in chapter 2 not definitively test the theories described above, it does offer evidence useful in evaluating the manner in which they treat foreign security threats. Specifically, failing to observe a positive correlation between threats and military technology innovation would have constituted disconfirmatory evidence of the explanations offered by Posen, Dombrowski and Gholz, Taylor, and Waltz. The fact that such correlations were observed, and were found to be robust, bolsters these theories.

6.1.2 On the University's Role in the Commercialization of Knowledge

The finding, presented in chapter 5, that university patents are substantially more highly cited and more general than corporate patents has implications for the literature on the changing role of the university in the commercialization of knowledge. Specifically, my finding supports the notion that the university is increasingly assuming an active role in commercialization. Below I summarize this literature and place my results in this larger scholarly context.

Youtie and Shapira (2008) propose a three-stage model of the transition of university operations with regards to the storage, production, and transmission of knowledge. This model is based on the historical transition of a prototypical Western university. The model identifies three university stages – storehouse, factory, and hub – where each stage is defined by the manner in which a university interacts with knowledge.

Universities operating in the initial ("storehouse of knowledge") mode primarily serve a pedagogical function. Explicit knowledge (largely stored in libraries) and tacit knowledge (possessed by faculty) are transmitted to students primarily via reading, classroom instruction, and the pupil-tutor relationship. The observed activities for this mode are thus pedagogical in nature, and include: the offering of courses towards degrees or certificates, professional training, and the operation of student exchanges and "study abroad" programs.

The primary novel function associated with the transition to the "knowledge factory" stage is the conduct of research. Universities operating in this second stage place increased attention on the "pursuit of scientific research based on rational inquiry and experimentation" (Youtie and Shapira 2008: 1189).

Whereas the novel functions associated with a "knowledge factory" focus on the production of knowledge, those for "knowledge hub" relate to its transmission. Universities operating in this stage act as an embedded *animateur* within their regions, actively linking research to commercial ends. Within this stage, commercialization of research and support for innovation is often linked to an economic development mission of creating new innovative businesses and stimulating economic growth through them. Besides the assumption of boundary-spanning functions, this stage is "associated with increased attention and weight to tacit knowledge especially in technology and regional interaction" (Youtie and Shapira 2008: 1190). At first glance, the notion of a university as a knowledge or innovation hub may not seem very different from previous paradigms of university function based on the generation and distribution of knowledge. Indeed, even a university operating as a quintessential "knowledge factory" did not horde new knowledge within its borders; it distributed it through publication and education. The novel feature of an innovation hub is thus not the transmission of new knowledge, but rather the intentional (i.e., through polices and novel organizations) distribution of *tacit* knowledge throughout a system.

The expansion in the functions undertaken by universities corresponds to a change in the way that the academy relates to its environment. During the storehouse mode, universities were enclaves of knowledge; isolated from their surrounding geographies. As universities added research to their portfolios, external ties to local firms developed. However, there remained two degrees of separation between universities and the wider economy. That is, universities interacted with firms whom, in turn, interacted with markets. However, as universities have assumed an active role in the commercialization of knowledge, the intermediary role of firms has reduced.

Empirical research into universities' success in generating economic activity in their surrounding regions has been mixed. Di Gregorio and Shane (2003) point out that while universities such as MIT and Stanford have been responsible for producing a large number of startups, comparable universities in terms of research budget such as Duke and Columbia have produced comparatively few new firms. Similarly, university incubators have had varied success in producing successful ventures. While there has been relatively little inquiry into the sources of this variation, two 2005 papers by Rothaermel and Thursby investigate two plausible determinants: university-firm linkages and university-firm knowledge flows. The authors find that university-firm linkages such as a tie to a university faculty member decrease the likelihood of firm failure, yet delay firm graduation from an incubator (Rothaermel and Thursby 2005a). However, when the authors assess whether knowledge flows (measured by whether the incubated venture procures a university licenses or cites university-held patents in its own patents) affect firm performance, they find little evidence that university knowledge flows to incubated firms improve venture performance (Rothaermel and Thursby, 2005b).

In contrast to the ambivalent results of previous research, the results presented in chapter 5 offer clear support for Youtie and Shapira's thesis. I find that universities are producing patents – possibly the quintessential example of knowledge commercialization – that are particularly useful in stimulating subsequent patenting activity. In the parlance of Youtie and Shapira, I find evidence that universities are acting in the role of knowledge hub or as the *animateur* of subsequent technological progress. While the research design employed in chapter 5 does not shed light on whether universities are effective at generating start-ups, the impact of university patents suggests that the commercialization impact of universities is significant.

6.2 Contribution to Social Science Methodology

The primary methodological contribution of this dissertation has been in the application of scientometric techniques to the topics of military technology innovation and military technology diffusion. The contribution follows from the fact that many of the subcomponents of military weapons systems are patented. In essence, the major military weapons systems – the same systems that are typically the subject of case-based research – are comprised of patented subcomponents. This allows for the application of well-established techniques of scientometrics such as patent analysis and patent citation analysis. Chapters 2 and 4, respectively, provide a detailed account of the construct validity of patents and patent citations as measures of military technology innovation and diffusion.

Besides opening the study of military technology innovation and diffusion to statistical treatment, the use of patent data allows for the measurement of incremental technological change. The focus of prior research has tended to focus on revolutionary technologies such as tactical nuclear weapons (Evangelista 1988), fleet ballistic missile (Sapolsky 1972), and the Trident II missile system (Coté 2006). Indeed, Evangelista is explicit in omitting incremental change from consideration, stating, "This term [technological innovation in weaponry] does not refer to the incremental improvements in the characteristic of weapons that arguably constitute the main activity of military research and development" (Evangelista 1988: 51). However, MacKenzie (1989) observes that incremental technological improvements can have significant impact on aggregate military capacity.[70]

Besides allowing for the measurement of incremental technological change, the use of patent data has several benefits relative to alternative measures. First, compared to other measures of innovation such as new product counts or high tech exports, patents are both geographically and temporarily proximate to the location of invention. In terms of geography, the patent of a subcomponent of an American product may be held by a French entity. To equate where a product or technology is produced or to assign credit to the home country of the technology integrator is to commit a fallacy of composition. Failure to consider the source of each component part of an invention is to lose data.[71] In regards to time, because patents (in that they are typically subcomponents) are further upstream that products, the patent filing date is a closer approximation of the time of invention that the product release date or the year or export. The relative utility of patents to end product as measures of innovation is especially true in the case of weapons systems, which are particularly complex, often involve a technology integrator, and can take decades to complete (Lichtenberg 1995; Mowery 2010).

Various scholars have noted the failure to apply large sample research methods to the topic of military technology innovation and the shortcomings of existing case-based approaches. For example, Mowery laments the lack of statistical treatment of military

[70] MacKenzie gives the example of strategic ballistic missile guidance as an important military technology that emerged through a process of gradual improvement.

[71] Security scholars are aware of the globalization of military technology production. Gholz (2007) and Brooks (2007a, 2007b) carefully trace the manner in which the fragmentation of production processes may affect the distribution of power and the prospects for peace. While Brooks contends that greater integration of commercial processes increases the probability of peace between great powers, Gholz is pessimistic regarding the capacity of globalization to pacify.

technology stating, “few quantitative studies of these issues [the effects of military R&D spending on the larger innovation system] have used the types of indicators (e.g., patents) that have been employed in other empirical studies of the sources and effects of innovation” (Mowery, 2010: 1235).

Similarly, in his review of Evangelista (1988), MacKenzie advocates for alterative methodologies claiming, “the case-study approach typical of most of the empirical work on technology and the arms race in next to useless when it comes to understanding incremental change. In their focus on a particular innovation or weapon system, case studies are poorly equipped to deal with the cases and consequences or changes that happen gradually over decades, such as the development of state-of-the-art of an incremental technology” (MacKenzie 1989. 172). By developing a method of measuring military technologies in large aggregates and thus opening the subject of military technology innovation and diffusion to scientometric and statistical techniques, this dissertation has attempted to answer address the shortcomings noted by Mowery and MacKenzie.

6.3 Suggested Extensions

6.3.1 Linking Particular Technologies to Particular Threats

The measure of military technology innovation used in chapter 2 does not differentiate between types of military technologies. Technologies meant to enhance a state’s offensive capabilities are not differentiated from defensive technologies. Land-based technologies are not distinguished from maritime or air technologies. At the same time, the measure of threats does not distinguish between types of threat.

The failure to distinguish between types of technologies and threats points towards a means of further testing the explanatory merit of Threat-Capacity theory. Scholars have observed that the focus of a state's military technology development orients towards the particular threats it faces. For example, Murray notes that the Japanese and American interest in amphibious technologies appears to stem from the nature of the War in Pacific during World War II. Similarly, the development of the Iron Dome missile defense system was accelerated following the second Lebanon war in 2006 during which over 4,000 rockets were shot at Israel injuring thousands and killing hundreds.

Linking particular technologies to particular threats would go far in bolstering Threat-Capacity theory and elucidating the causal processes underlying the correlational finding described in chapter 2. Such a research project would simply require the coding of technologies and threats. If particular threats (e.g., incoming rockets from Lebanon) can frequently be linked to particular military technology innovations (e.g., Israel's development of the Iron Dome system), the explanatory power of Threat-Capacity theory will be enhanced.

Preliminary analysis of this sort reveals promising results. Below I plot the relationship between improvised explosive devises (IEDs) fatalities and IED patents.[72] The first IED fatality in Afghanistan was in 2002. There were, in fact, four IED deaths in 2002.

[72] Patents results based on search for "improvised explosive device" or "IED" of US military patent abstracts. The patent dataset is that employed in chapter 2 of this dissertation. IED fatality data refers to the IED fatalities from Operation Enduring Freedom (OEF). OEF fatality data comes from http://icasualties.org/oef/

The first patent for an IED countermeasure was granted in 2003. This observation coupled with the plot provided below provides strong evidence that particular military technology innovations can be linked to particular threats. Figure 3 plots IED fatalities against IED patents on a shared horizontal time axis. The plot reveals that the onset of patenting for IED countermeasures corresponds closely to the threat posed by IEDs.

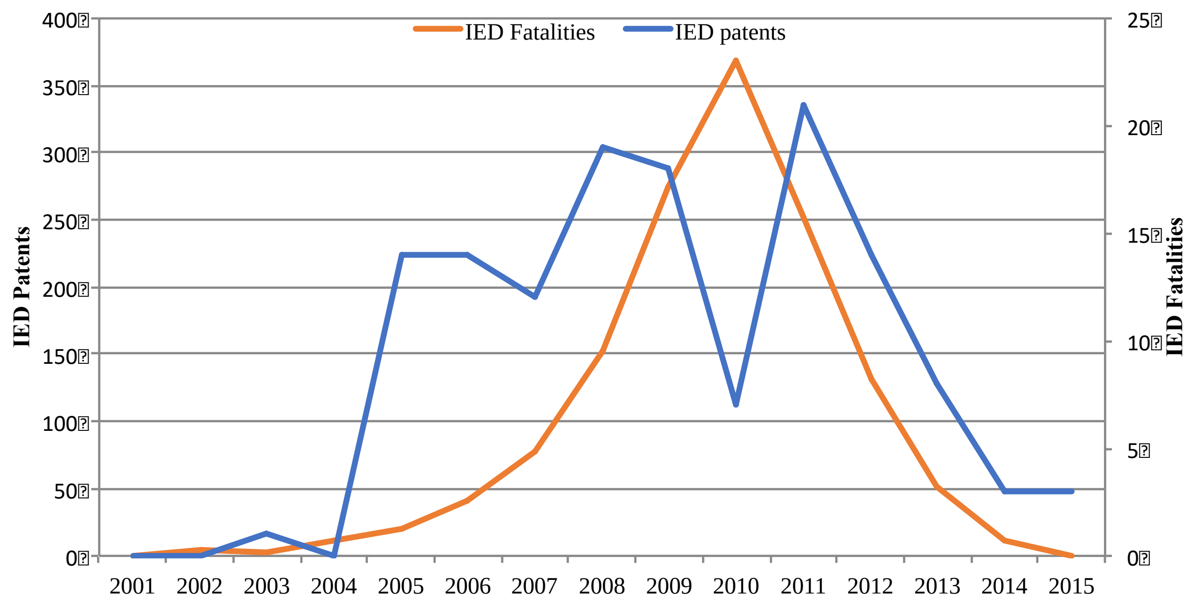

Figure 3 IED fatalities against IED patents, 2001-2015

6.3.2 Additional Testable Hypotheses on Military Technology Diffusion

Chapter 4 evaluated four hypotheses. The literature, however, makes several additional claims that, to the best of my knowledge, have yet to be evaluated empirically. With the hope that others might examine their veracity, two of these untested claims are elaborated here.

H2 from chapter 4 states that the military technologies that are developed by firms will diffuse more readily than those developed by government agencies. A straightforward corollary to this hypothesis can be drawn regarding government-firm collaboration. The reasoning underlying this alternative claim parallels that provided in support of H2.

Alic et al. (1992) and Bellais and Guichard (2006) argue that that firms' profit motive and greater relative capacity to adapt, mass-produce, and distribute nascent technologies will increase the likelihood that firm-developed military technologies will have extra-defense impact. For example, while the Department of Defense funded and drove demand for early research on lasers, participation by industry was critical in broadening the range of products that incorporated the technology and reducing production cost (Alic et. al 1992; Bromberg 1991). A government-firm collaboration is likely to be possessed of a higher proportion of profit motive than projects that are exclusively government-run. Thus, as a corollary to H2, the following hypothesis might be tested: *The diffusion of military technologies developed by government-firm collaboration will be greater than those developed exclusively by government agencies.*

A second untested hypothesis relates to the relationship between diffusibility and where a technology is within its lifecycle. Cowan and Foray (1995) propose a framework in which the diffusion of a military technology will vary inversely with respect to its stage in its life cycle. During the early stage of a technology's life, military and civilian actors are argued to have a mutual interest in generating and acquiring "generic information about the technology" (Cowan and Foray 1995:857). As a technology develops, the information required by each set of actors becomes more specialized and thus of less mutual utility. As the pursuit of generic information is replaced by that of more specialized information, diffusion is purported, by the authors, to decline.

Case study based empirical research supports the contention that as a military technology becomes more specialized its diffusibility decreases. Mowery (2010) studies the impact of defense R&D expenditure on three civilian industries – commercial aircraft, machine tools, and information technologies – and finds the influence of defense funding declines as technologies mature. For example, over the period of 1945-2000, military-sourced R&D as a percentage of total R&D expenditure for the commercial aircraft sector was relatively constant. However, the impact of this spending on the early development of civilian jet engine, avionics, and airframes, was greater than it was once these technologies had matured. Cowan and Foray's claim regarding the negative relationship between diffusibility and the maturity of a military technology might be articulated as follows: *Diffusion will be greater for military technologies that are early in their life cycle.*

6.3.3 Identification of General Purpose Technologies

As noted in chapter 5, the identification of general purpose technologies faces what may be deemed a classification problem. That is, deciding which technologies belong to the GPT category and which do not has, in the past, depended on the discretion of the individual scholar scrutinizing the technology. One upshot of this classification problem has been that a large number of technologies have been put forth as GPTs yet there remains considerable disagreement in regards to the fit of these classification decisions. For example, technologies proposed as potential GPT candidates include the means of generating electricity (Jovanovic and Rousseau 2005), the steam engine (Bresnahan and Trajtenberg 1992), chemical engineering (Helpman 1998: 167-192) the Internet (Clarke et al. 2015), nanotechnology (Shea et al. 2011; Youtie et al. 2008), bioinformatics (Appio et al. 2017), and the Cohen-Boyer rDNA technology (Feldman and Yoon 2011).[73] Yet others (Moser and Nicholas 2006) have questioned whether some of these technologies truly constitute GPTs.

The failure to converge on an agreed upon set of GPTs presents an interesting literature gap. I believe aspects of the measurement strategy and research design employed in chapter 5 may prove useful in filling this gap. In particular, chapter 5 avoided the classification problem by using a non-discrete means of measuring generality and importance. The same approach could be taken for other characteristics of GPTs in order to arrive at a set of GPTs that avoid an arbitrary classification decision.

Jovanovic and Rousseau (2005: 1185) provide a commonly used definition of general purpose technologies that can be used towards this end. The authors define a GPT as a technology characterized by three traits: pervasiveness, innovation spawning, and improvement. According to the authors, a GPT meets the pervasiveness criterion if the technology has “spread to most sectors” (Jovanovic and Rousseau, 2005: 1185). This

[73] While the vast majority of research on GPTs focus on physical technologies (and the embedded tacit knowledge), several scholars have identified the characteristics of GPT in less tangible forms of innovation such as business models (Gambardella and McGahan, 2010) and organization forms (Lipsey et al. 2005). Others have used a taxonomical approach; defining five classes of GPTs: ICTs (e.g., the computer), materials (e.g., Iron), power sources (e.g., steam engines), transportation (e.g., railways), and organization forms (e.g., assembly line manufacturing) (Lipsey et al. 2005).

criterion could be measured using the generality index used in chapter 5. The authors contend that a technology is innovation spawning if it "makes[s] it easier to invent and produce new produces or processes" (Jovanovic and Rousseau, 2005: 1185). This definition corresponds closely the definition of a forward patent citation. Thus, this second trait could be measured using the importance (five year forward citation count) metric that was employed in chapter 5 of this dissertation. Improvement refers to the condition that a GPT "should get better over time and, hence, should keeping lowering the costs of its users" (Jovanovic and Rousseau 2005: 1185). Chapter 5 does not include a metric of improvement, however, data on prices is widely available. Thus, in order to arrive at a set of technologies that correspond to Jovanovic and Rousseau's definition, a scholar could simply employ the multi-dimensional ranking strategy employed in chapter 5. More precisely, an interested scholar would simply need to rank a set of candidate technologies on each criterion, determine an appropriate threshold level (in chapter 5, I used quintiles, but a stricter threshold may be deemed appropriate) and determine which of the candidate technologies surpass the threshold for all three dimensions. The result would be a, likely small, subset of technologies that closely conform to Jovanovic and Rousseau's three-part criteria of a GPT.

6.4 Limitations

Chapter 2 departs from many previous theoretical treatments of military innovation in that it explicitly disaggregates military technology innovation and military doctrine innovation. This parsing can be justified in at least two ways. First, I can think of no sound a priori conceptual rationale for marrying these two distinct types of innovation. An analogy to the study of civilian innovation is illustrative. Military technology innovation is akin to product innovation. Innovation in military doctrine is more closely analogous to process innovation or organizational innovation. If the civilian innovation literature were to indicate convergence towards a single theory of product, process, or organizational innovation, maintaining an encompassing definition of military innovation may be justified. However, the opposite appears to be the case.[74] Second, as described in chapter 2, to combine innovation in military doctrine into a single dependent variable would be to introduce endogeneity into the object of scrutiny.[75] This is because military technology has been shown to drive doctrine and doctrine has been shown to affect technological innovation.

The significant role of military doctrine in affecting military outcomes such as the duration and outcome of armed conflict is well documented. For example, Posen (1984) provides a leading account of the interaction between doctrine and national security strategy. Posen defines military doctrine as the component of a country's national security strategy that determines *what* and *how* military means are employed towards the realization of the end of the security priorities contained in a country's national security strategy (Posen 1984:13). Posen argues that innovation in military doctrine affects a country's

[74] One means of supporting this claim is simply by considering the degree with which firms have developed specializations in either process or product innovation. Firms such as Walmart and Zara compete based on the optimization of supply chains, logistics, and inventory management (i.e., by means of process innovation). Firms such as IBM, Apple, and Samsung specialize in the development of novel products. If the determinants of product and process innovation were largely similar, specialization would be the exception. However, specialization appears to be the norm as firms (such as Apple) capable of both product and process innovation are rare.

[75] While chapter 2 elaborates the sources of this endogeneity, the feedback loop of concern here can be easily observed in Evangelista's definition of military technology innovation. Evangelista defines military technology innovation, in part, as those technological changes that drive doctrinal change, stating, "Technological innovation in weaponry is defined here as the development of a new military technology that leads to significant changes – for example, in the realm of strategy, in the organization of military forces, or in the distribution of resources among services" (Evangelista 1988: 51).

national security strategy through two distinct channels. First, innovation can increase or decrease the integration of military resources with the political goals they serve. When political objectives and military means are integrated, political leaders will have a clear understanding of the capabilities and limitations offered by their military resources. In such instances, there is increased likelihood that political objectives are cognizant of state's (and that of its rivals) military capacity. An increase (decrease) in military-political integration constitutes an improvement (diminishment) to the doctrine. Thus innovations in military doctrine, all else constant, that increase integration can be considered desirable.

Second, innovation of military doctrine can affect a state's probability of military defeat. Posen notes that as a state's projected allies and enemies change, so does the appropriateness of given military doctrine. Failure to adjust adequately to such changes affects the likelihood that a given military doctrine will realize national security objectives. Besides an exogenous shift in terms of allies or enemies, Posen contends that changes in the technological environment constitute another form of innovation that may affect a state's chances at military victory. As the relative balance of effective use of technological change will, in part, determine the effectiveness of a military doctrine, decisions regarding which technologies are pursued become paramount.

While the positive feedback loop between technological and doctrinal change poses a measurement problem, the documented interaction between military doctrine and technology suggests one shortcoming of the analyses presented here. In particular, by focusing exclusively on military technology innovation (chapter 2) and organizational change (chapter 3), the important role of doctrine is overlooked. While I believe that the increased precision in measurement that is gained from focusing exclusively on a single type of innovation in a given sub-study justifies the exclusion of doctrine, it is important to note that a complete understanding on the effect of technological or organization change on militaries requires consideration of the interaction of these factors with doctrinal change.

CHAPTER 7. APPENDIX PATENTS AS OPEN SOURCE INTELLIGENCE

Working with the data used in this dissertation has convinced me of the merit of patent and patent citation data as plausible proxies for various military technology innovation processes. Whereas within the body of the dissertation I use these data to engage academic scholarship, I believe they may serve more practical ends. In particular, I believe patent and patent citation data may be leveraged as a source of open source intelligence.

In this appendix I analyze three samples of military technology patents to illustrate the utility of these data in gleaning information regarding state-level military technology innovation. The tables and visualizations presented below mean to provide an indication of the type of information that may be assembled by applying scientometrics to military patenting. The analyses provided here are by no means exhaustive; rather they hope to serve as a proof of concept regarding a novel source of military technology intelligence.

7.1 Mahnken's Intelligence Indicators of Innovation

Thomas G. Mahnken observes that intelligence agencies' record in detecting foreign military innovation is "less than stellar" (Mahnken 1999: 26). Mahnken cites as exemplary of his claim the US intelligence community's failure to provide warning of India's 1998 nuclear test and the failure of British intelligence services to anticipate Germany's development of radar in the build-up to World War II. Chapter 3 of this dissertation described the US intelligence community's failure to attain an accurate understanding of the USSR's ballistic missile capacity prior to the 1957 launch of Sputnik. The CIA's erroneous 2002 estimates regarding Iraq's reconstitution of its WMD program and its failure to provide warning of North Korea's 2006 nuclear detonation could also be added to this list.

However, according to Mahnken, this pattern of technological surprise need not persist. Military innovation is characterized by two attributes that facilitate its detection. First, innovation takes considerable time or as Mahnken's writes, "While the appearance of new combat methods is a common source of surprise, such innovations do not as a rule spring forth overnight" (Mahnken 1999: 30). Second, innovation often leaves a trail of observable markers. Regarding the tendency for military innovation to leave behind evidence, Mahnken writes, "the process of developing novel ways of war may [] yield a considerable number of indicators" (Mahnken 1999: 30). These characteristics – the delay between the conceptualization of an innovation and its eventual use and the presence of observable correlates – open military innovation to scrutiny.

Mahnken identifies a three-phase process by which militaries innovate: speculation, experimentation, and implementation.[76] For each phase, he identifies a set of potential indicators. Table A.1 recreates Mahnken's three-phase framework and provides the associated indicators. I have added additional indicators to the table based on where patent and patent citation data might be used to supplement the framework.

Speculation refers to the ideational phase of innovation. This phase is characterized by the identification of a problem or opportunity and the commencement of systematic thinking regarding how to solve the problem or exploit the opportunity.[77] The evidence that speculation has occurred or is occurring – i.e., its indicators – include white papers, journal articles, speeches, or records indicating the formation of exploratory groups. As patents are essentially innovative outputs (i.e., they appear further downstream in the innovative process), patent data are of limited utility during this phase. It is possible, however, that the scientometric techniques presented below could be applied to a corpus of white papers or journal articles to glean technical intelligence on the speculation phase.

Mahnken's second phase, experimentation, refers to attempts to carry the most promising results of the speculation phase into practice. Indicators of experimentation include the establishment of an organizations charged with experimentation, the existence

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[76] As described in chapter 2 of this dissertation, scholars of military innovation generally combine doctrinal and technological innovation into a single object of scrutiny: military innovation. Mahnken is no exception. The additions that I have made to his framework, however, focus exclusively on technological innovation. However, it is likely that additional intelligence on a state's military technology priorities would shed light on potential doctrinal change.

[77] This definition corresponds conveniently to the DOD budget category 6.2 (applied research). In particular, the DOD defines, applied research as "Systematic study to gain knowledge or understanding necessary to determine the means by which a recognized and specific need may be met."

of a testing grounds, field testing, war gaming, and even wartime experimentation. It is during this phase that patent data holds the most promise. In a technology's lifecycle, patenting (when it occurs) almost always precedes the appearance of an end product. This temporal gap between patenting and the technology's use is likely to be even larger when the products in question are kept secret until they are used in conflict. Thus, patent application data provides the means of identifying a military technology prior to its manifestation in combat or even testing.[78]

During the implementation phase a subset of innovations are incorporated into a military's bureaucracy. Because this phase is characterized by significant and enduring organizational change, indicators are more plentiful than during the first two phases. Indicators of implementation include the existence of a formal transformation strategy, establishment of new units, new doctrine, new career paths, and changes to military education curricula. Patent and patent citation data also hold promise during this phase. For example, a patent covering the configuration of a weapons' system may indicate that such a system is approaching completion (i.e., that critical subcomponents are available and that experimentation is nearing completion).[79] Further, the identification of clusters – either in terms of technological fields or organizations – may reveal information regarding a country's innovation priorities and process.

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[78] All of the caveats regarding the limitation of patent data also hold here. For example, intellectual property that is protected via secrecy rather than patenting will be omitted from patent-based analyses. Thus, the use of patents as means of detecting military innovation should supplement other methods that seek to identify technologies that are protected via secrecy.

[79] For example, when Rafael Advanced Defense Systems file patent number US20060238403 in 2003 for a "Method and system for destroying rockets" the probability that the Iron Dome missile defense system was approaching operability increased.

Table 20 Indicators of Military Innovation

Speculation	• Publication of concept papers, books, journal articles, speeches, • and studies regarding new combat methods. • Formation of groups to study the lessons of recent wars. • Establishment of intelligence collection requirements focused upon foreign innovation activities.
Experimentation **II.a Tech. Experimentation**	• Existence of an organization charged with innovation and • experimentation. • Establishment of experimental organizations and testing grounds. • Field training exercises to explore new warfare concepts. • Wargaming by war colleges, the defense industry, and think tanks regarding new warfare areas. • Experimentation with new combat methods in wartime. • **Patent Applications.**
Implementation **III.a Tech. Implementation**	• Existence of a formal transformation strategy. • Establishment of new units to exploit, counter innovative missive areas. • Revision of doctrine to include new missions. • Establishment of new branches, career paths. • Changes in the curriculum of professional military education • institutions. • Field training exercises to practice, refine concepts. • **Patent Applications** • **Emergence of Patent Clusters (by technology area, by organization)**

Note: Non-bold items come directly from Mahnken's (1999) proposed framework. Bold items are new and represented the proposed role of patent and patent citation analysis as indicators of military innovation.

7.2 Data and Sampling

In the analyses to follow, I use two sampling strategies. The strategy employed depends on the purpose and target of the analysis. The first strategy aims to facilitate analysis that provides a broad overview of recent military technology patenting. These analyses aim to answer questions such as:

- Who are the primary countries and organizations involved in the development of military technologies?
- In what technological areas has recent military technology innovation focused?
- What are the network characteristics of military technology patent families?

To arrive at the first sample of patents, I begin by searching the Derwent Innovation Index (DII) for Derwent Class Code "W07" over the period 2013 to 2017 (inclusive). On February 21, 2018, this search yielded 13,656 unique patents.[80] For each patent, the full results were downloaded as text files. These text files are, conveniently, fielded, and can thus can be parsed based on field indicators (e.g. TI = Patent Title, PN = Priority Number). VantagePoint, a text mining software, was used to parse the text files.

The second sampling strategy seeks to reveal information regarding the military technology activity of particular countries. South Korea and China were chosen as target countries. In effort to identify potential time trends, the period of analysis is extended to twenty years (1996-2015). Questions that might be answered using the second sampling strategy include:

- Who are the primary organization involved in the development of military technologies in South Korea/ China?

[80] Technically, the results refer to patent families (the set of patents granted in various countries for a single underlying innovation). In many cases, the use of patent families as units of innovation is preferred to patents because the use of patent families avoids double counting a single innovation that has been filed in more than one jurisdiction.

- How has the contribution of these organizations changed over time?
- What are the collaboration network characteristics of these organizations?
- In what technological areas has military technology innovation focused in South Korea/ China?
- What is the rate of military patenting growth in South Korea/ China?
- At what level is military technology patenting likely to occur in South Korea/ China in the next few years?
- At what level is military technology patenting in a particular technological sub-field likely to occur in South Korea/ China in the next few years?

To arrive at the country-specific samples, I begin searching the DII for Derwent Class Code "W07" without a restriction on period. This gives 40,927 results. These results are downloaded and then parsed using VantagePoint. I then exclude patents whose basic patent year does not fall between 1996 and 2015. This leaves 32,096 patents. Finally, to arrive at the China sample (6,373 patents), I limit the dataset to patents with a basic patent in China.[81] The same is done to arrive at the South Korean sample (1,553 patents). Finally, in order to compare the S-curve for autonomous military systems of South Korea and China to that of the United States, I also create a sub dataset for the US.

7.3 Sample 1: All Military Technology Patents, 2013-2017

[81] The basic patent country refers to the first country in which a patent is filed. It is thus an appropriate measure of an innovation's country of origin.

Table 21 Top 30 assignees, 2013-2017

Organization	Military Tech. Patents (2013-2017)	Country of Origin	Organization Type
Agency for Defense Development	218	South Korea	Government
Boeing	161	US	Firm
Raytheon	144	US	Firm
Thales	124	France	Firm
BAE Systems	110	UK	Firm
Lockheed Martin	87	US	Firm
Lig Nex1	82	South Korea	Firm
US Sec Of Navy	81	US	Government
Shepelenko V B	75	Russia	Individual
US Sec Of Army	64	US	Government
China Academy of Launch Vehicle Tech.	56	China	Firm
MBDA Deutschland	51	Germany	Firm
Huanic	49	China	Firm
Li X	47	China	Individual
Nanjing University of Science and Tech.	47	China	University
Diehl Defence	45	Germany	Firm
Rockwell Collins	45	US	Firm
Liaoning Police Officer Junior College	42	China	University
Russian Federation Min Defence	42	Russia	Government
Xi Y	42	China	Individual
Beijing Institute of Technology	40	China	University
Mitsubishi	39	Japan	Firm
Ordnance Engineering College	39	China	University
Li Y	36	China	Individual
Wang H	35	China	Individual
Efanov V V	34	Russia	Individual
Omnitek Partners	33	US	Firm
Harbin Institute of Technology	31	China	University
Anhui University of Science and Tech.	31	China	University
Liu Y	30	China	Individual

Table 22 Top 15 countries, 2013-2017 [82]

Country	Patents	% of Total
China	5818	42.60%
US	3074	22.51%
Russia	1230	9.01%
Korea	1031	7.55%
WIPO	754	5.52%
Germany	433	3.17%
EPO	327	2.39%
Japan	237	1.74%
France	189	1.38%
UK	119	0.87%
India	91	0.67%
Turkey	67	0.49%
Taiwan	65	0.48%
Poland	44	0.32%
Spain	42	0.31%
Brazil	30	0.22%
Canada	26	0.19%

[82] Based on basic patent country. Also included are patents where the basic patent was filed with the European Patent Organization (EPO) and the World Intellectual Property Organization (WIPO).

Table 23 Top 30 Phrases (NLP applied to patent titles)[83]

NLP Phrases Patent Title	Patents
vehicle/ military vehicle	464
aircraft / military aircraft	446
controller	364
target	361
firearm	271
battery	253
shell	218
weapon	209
control unit	206
camera	202
sensor	197
gun	194
missile	190
power supply	189
motor	156
signal	156
surface	152
projectile	150
laser	134
display	132
light	124
circuit	113
antenna	111
control system	108
control	107
computer	106
lens	103
rifle	95
communication	91
power source	83

[83] While the Natural Language Processing (NPL) filter provided separate results for certain phrases (e.g., aircraft and military aircraft), I have combined such phrases in the provided list. Combined results are indicated with a "/" (e.g., "aircraft / military aircraft").

Table 24 Top 30 Phrases (NLP applied to patent abstracts)

NLP Phrases Patent Abstrat	Patents
target	1145
vehicle	884
structure	868
aircraft	845
power/ power supply	840
battery	533
data	532
gun	531
controller	530
firearm	517
shell	515
signal	514
distance	512
ammunition	498
missile	491
information	487
safety	463
laser	408
accuracy	380
communication	352
processor	352
switch	343
projectile	319
display	317
motor	310
control	304
antenna	302
range	260
lens	251
rifle	250

Table 25 Co-occurrence matrix, top 15 patent family countries (absolute values) [84]

	China	US	Russia	Korea	Germany	Japan	Canada	India	France	Australia	UK	Taiwan	Israel	Brazil	Spain
China	*6158*														
US	319	*3959*													
Russia	27	34	*1269*												
Korea	88	190	6	*1257*											
Germany	43	121	4	33	*503*										
Japan	149	229	13	75	23	*476*									
Canada	104	256	15	45	25	87	*292*								
India	78	168	14	47	22	58	69	*285*							
France	22	104	9	8	11	20	25	33	*248*						
Australia	42	163	4	31	15	39	100	58	8	*195*					
UK	18	107	2	12	12	15	25	33	11	37	*191*				
Taiwan	27	53	0	16	4	15	5	5	0	5	0	*125*			
Israel	14	97	13	21	11	15	32	27	11	20	7	1	*117*		
Brazil	52	79	6	20	12	35	53	44	9	22	8	3	11	*115*	
Spain	8	33	6	11	10	6	9	12	11	5	2	1	8	6	*94*

Table 26 Co-occurrence matrix, top 15 patent family countries (relative values)

	China	US	Russia	Korea	Germany	Japan	Canada	India	France	Australia	UK	Taiwan	Israel	Brazil	Spain
China	100.0%														
US	8.1%	100.0%													
Russia	2.1%	2.7%	100.0%												
Korea	7.0%	15.1%	0.5%	100.0%											
Germany	8.5%	24.1%	0.8%	6.6%	100.0%										
Japan	31.3%	48.1%	2.7%	15.8%	4.8%	100.0%									
Canada	35.6%	87.7%	5.1%	15.4%	8.6%	29.8%	100.0%								
India	27.4%	58.9%	4.9%	16.5%	7.7%	20.4%	24.2%	100.0%							
France	8.9%	41.9%	3.6%	3.2%	4.4%	8.1%	10.1%	13.3%	100.0%						
Australia	21.5%	83.6%	2.1%	15.9%	7.7%	20.0%	51.3%	29.7%	4.1%	100.0%					
UK	9.4%	56.0%	1.0%	6.3%	6.3%	7.9%	13.1%	17.3%	5.8%	19.4%	100.0%				
Taiwan	21.6%	42.4%	0.0%	12.8%	3.2%	12.0%	4.0%	4.0%	0.0%	4.0%	0.0%	100.0%			
Israel	12.0%	82.9%	11.1%	17.9%	9.4%	12.8%	27.4%	23.1%	9.4%	17.1%	6.0%	0.9%	100.0%		
Brazil	45.2%	68.7%	5.2%	17.4%	10.4%	30.4%	46.1%	38.3%	7.8%	19.1%	7.0%	2.6%	9.6%	100.0%	
Spain	8.5%	35.1%	6.4%	11.7%	10.6%	6.4%	9.6%	12.8%	11.7%	5.3%	2.1%	1.1%	8.5%	6.4%	100.0%

[84] Relative values are adjusted by the total number of patent families that a country hosts. For example, Brazil shares 52 patent families with China. Brazil is host to 115 instances of patents (the diagonal of the matrix). Thus, the relative value for Brazil is 52/115 = 45.2%. This measure thus adjusts for patent family output and gives a normalized measure of co-familiarity. The relative plot is particularly useful in understanding the US/ China relationship. While in absolute terms, the two states are co-family hosts for 319 patents, these only represent 8.1% of US hosted patent families and 5.2% of Chinese hosted patent families.

85

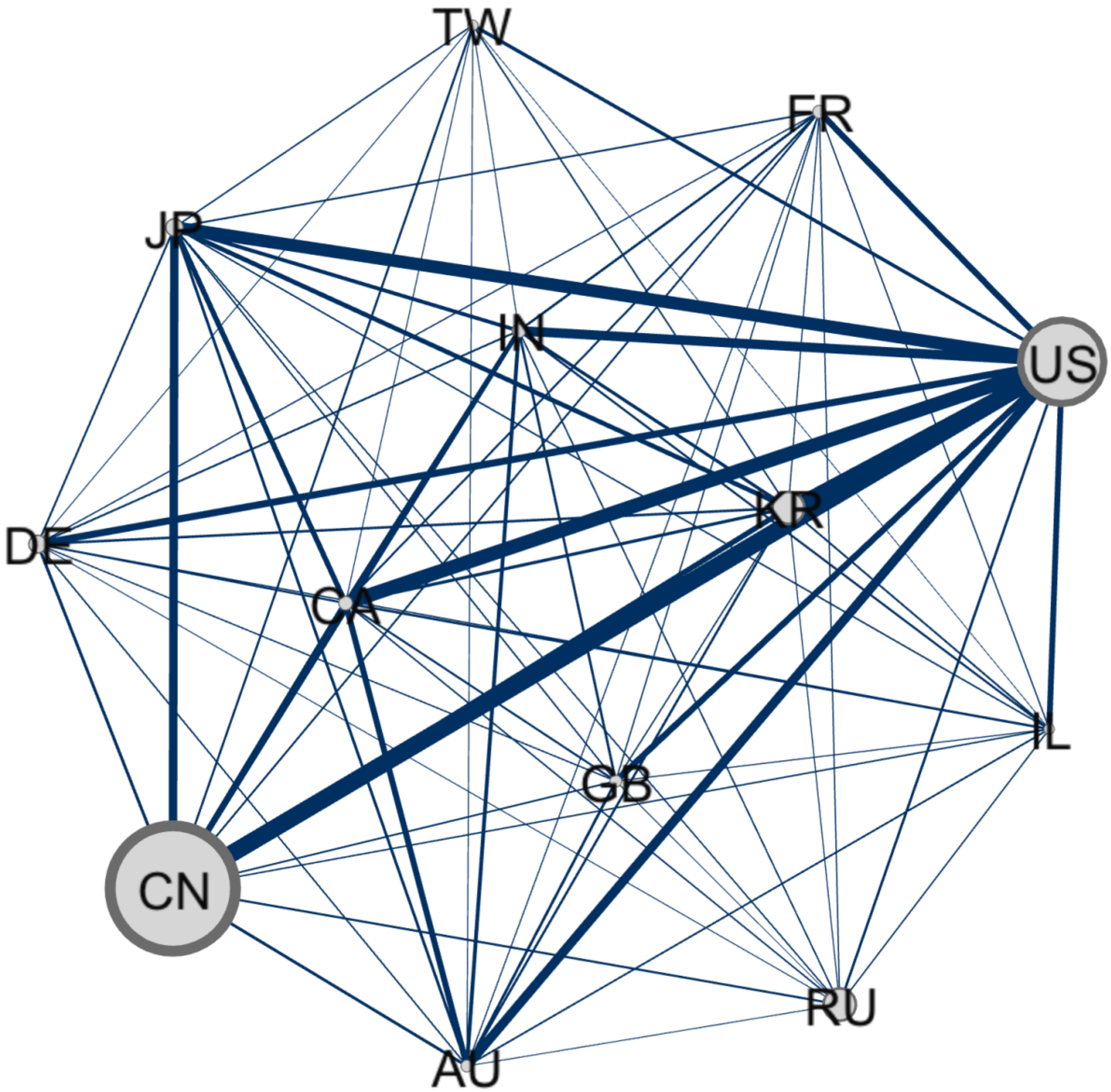

Figure 4 Network of top 15 patent families (full network)

[85] Network graphs were drawn using the Fruchterman-Reingold algorithm in Gephy.

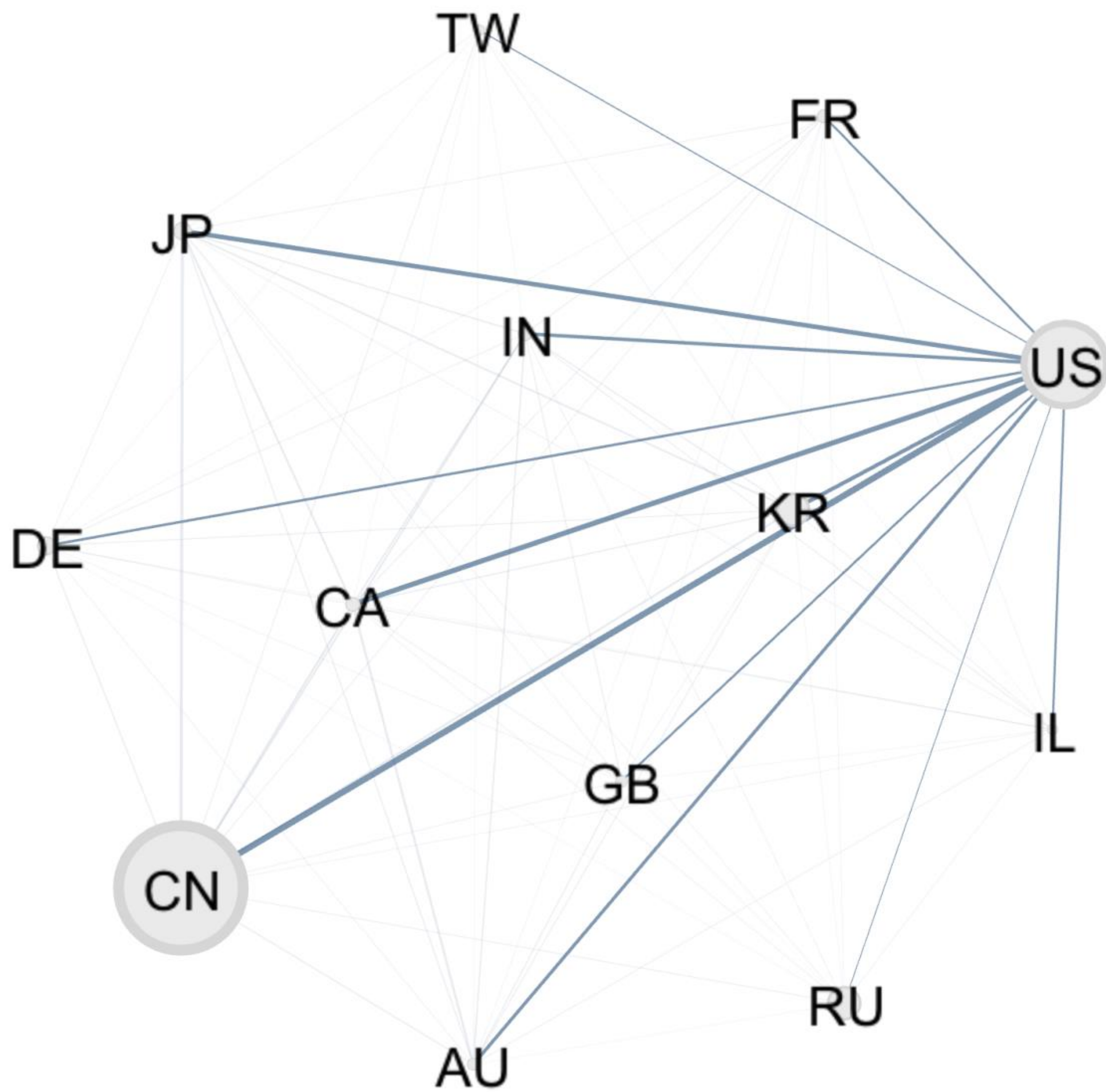

Figure 5 Network of top 15 patent families (US edges highlighted)

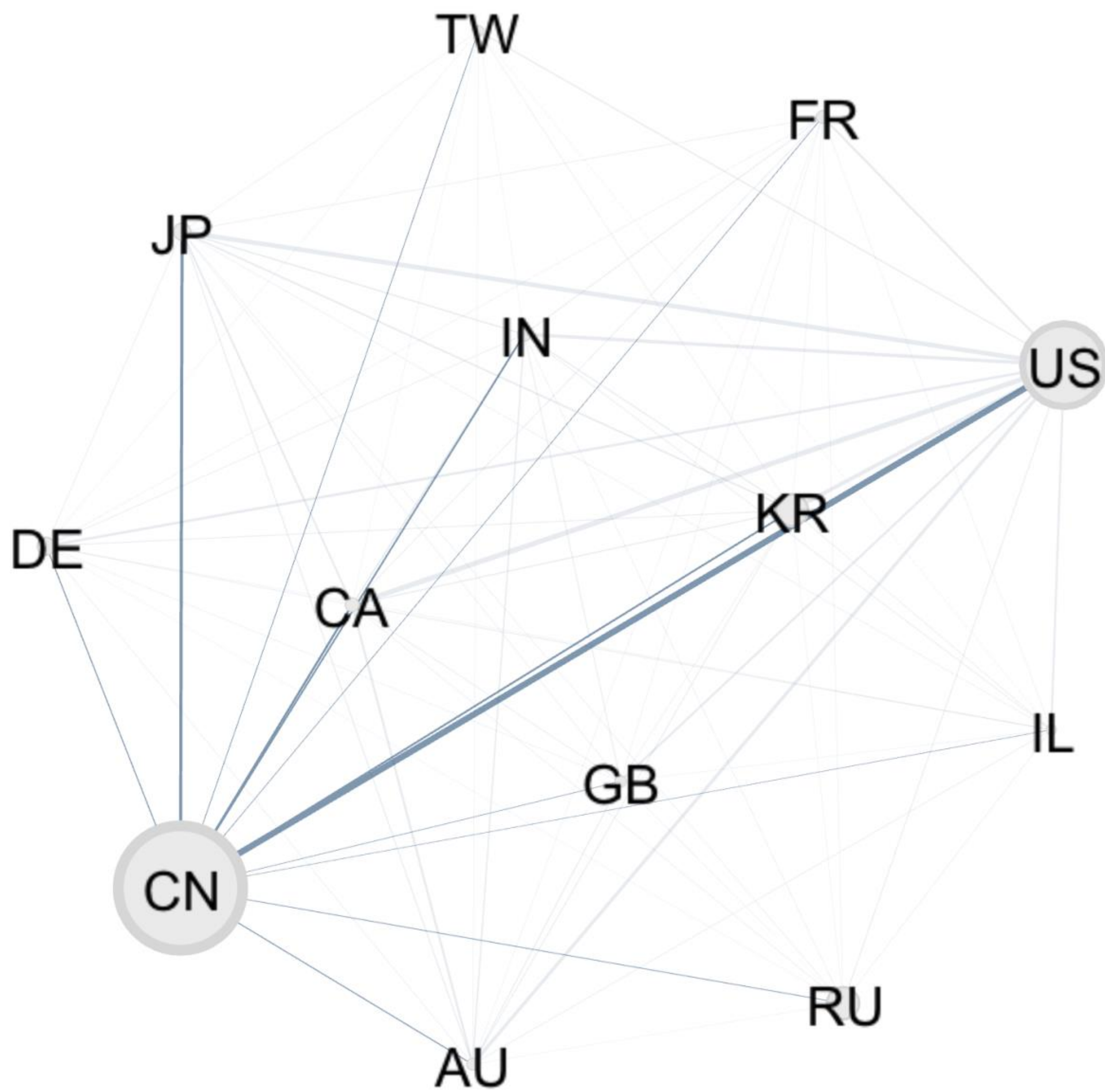

Figure 6 Network of top 15 patent families (China edges highlighted)

7.4 Sample 2: Chinese Military Technology Patents, 1996-2015

Table 27 Top 20 assignees, China

Organization	Military Tech. Patents (1996-2015)	Organization Type
Beijing Inst Technology	77	University
Chengdu Sainasaide Technology Co Ltd	70	Firm
Univ Beijing Aeronautics & Astronautics	64	University
Xian Huanic Optoelectronic Corp	61	Firm
Sun L	47	Individaul
Liaoning Police Officer Junior College	42	University
Shandong Shenrong Electronics Co Ltd	42	Firm
Wang H	41	Individaul
Xi Y	40	Individaul
China Acad Launch Vehicle Technology	34	University
Li Y	32	Individaul
Wang J	31	Individaul
Harbin Inst Technology	30	University
Li X	30	Individaul
Univ North China	26	University
Univ Zhejiang	26	University
Wang Y	25	Individaul
Guizhou Jiulian Industrial Explosive Material Dev. Co.	24	Firm
Hnegyang Tellhow Sci Tech Co Ltd	24	Firm
Univ Harbin Eng	24	University

Table 28 Top 12 phrases, China, (NLP applied to patent abstracts)

NLP Phrases Patent Abstract (China)	Patents
shell	375
military	350
gun	342
power supply	310
target	277
safety	275
battery	249
camera	244
laser	188
high stability	168
computer	162
detonator	146

Table 29 Top 10 IPC codes, China

IPC (4-digit) China	IPC	Patents
F41G	Weapon Sights; Aiming	655
F42B	Explosive Charges	641
F41B	Weapons For Projecting Missiles	554
F42C	Ammunition Fuzes	423
H04N	Electric Communication Technique	415
F41H	Armour	370
F41A	Functional Features or Details Common to Both Smallarms and Ordnance	340
F41J	Targets	279
G02B	Optical Elements	214
F21V	Functional Features or Details Of Lighting Devices	180

Table 30 Co-occurrence matrix, top 30 IPC codes, China

China	F41G	F42B	F41B	F42C	H04N	F41H	F41A	F41J	G02B	F21V	G03B	G01S	G06F	H04L	G01C	H02J	F41F	B60R	H05K	H01P	G01N	G05B	H04B	F41C	H01Q	G06K	G06Q	H01B	B64C	G08B
F41G	***655***																													
F42B	13	***641***																												
F41B	10	7	***554***																											
F42C	1	36		***423***																										
H04N	10	2	2		***415***																									
F41H	5	5	24		11	***370***																								
F41A	20	6	4		3	3	***340***																							
F41J	12	2				1	19	***279***																						
G02B	20	16			59	3	5		***214***																					
F21V	12	1	34		6	7			3	***180***																				
G03B	1	1	1		111	3			38	11	***145***																			
G01S	6	6	5		7	4	4	1	3	2		***139***																		
G06F	4	6			1	1	1		2	1		3	***127***																	
H04L	3			1	5		1	1	1			3	6	***116***																
G01C	8	6			7	1	3	1	1	1		13	2		***115***															
H02J	1	2	8		3	2				2			1	2		***107***														
F41F	14	12	4	1	3	2	6						1	2			***105***													
B60R			2		36		1		8	2	8				5		1	***102***												
H05K			1	2	4	9			1	3	2		4	1		2			***102***											
H01P		1		2																***100***										
G01N		8	1	1					1			3	2								***86***									
G05B	2	2	2	7	4		2		2		1	1	3	4	2	1	2	1			1	***85***								
H04B	1	1	2		2				4			2	1	13				1	1			1	***81***							
F41C	21	7			2		15	1		4					1	1		1						***78***						
H01Q		1										3			1			1	1	5			4		***78***					
G06K	5	4	3	2	6		1	1				2	5	1	2	1						1	1			***75***				
G06Q				2									5	2												6	***72***			
H01B				1						1									2									***69***		
B64C		5			3			1			4	3					1												***67***	
G08B		2	13		18	5				3		2	1	2		1						4	2	3		4	1			***66***

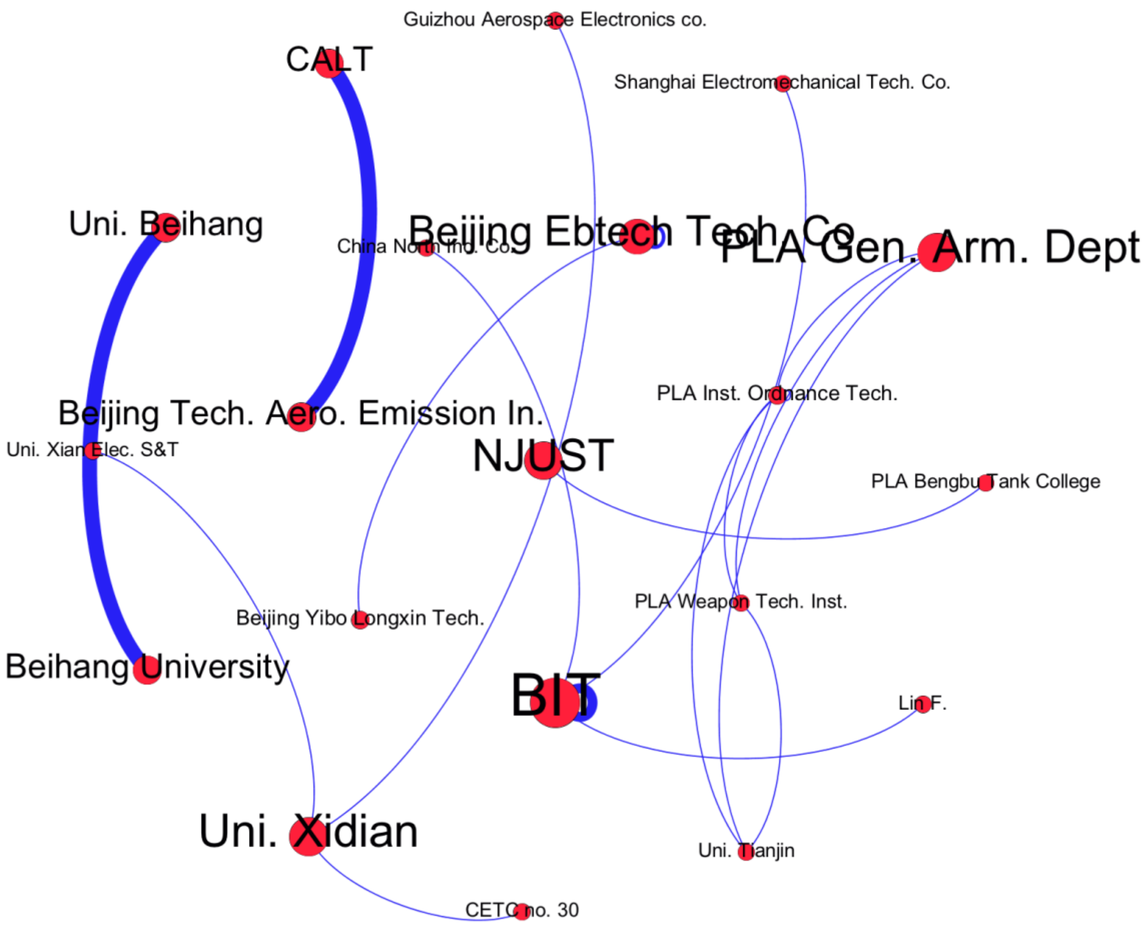

Figure 7 Collaboration network of top patent assignees, China

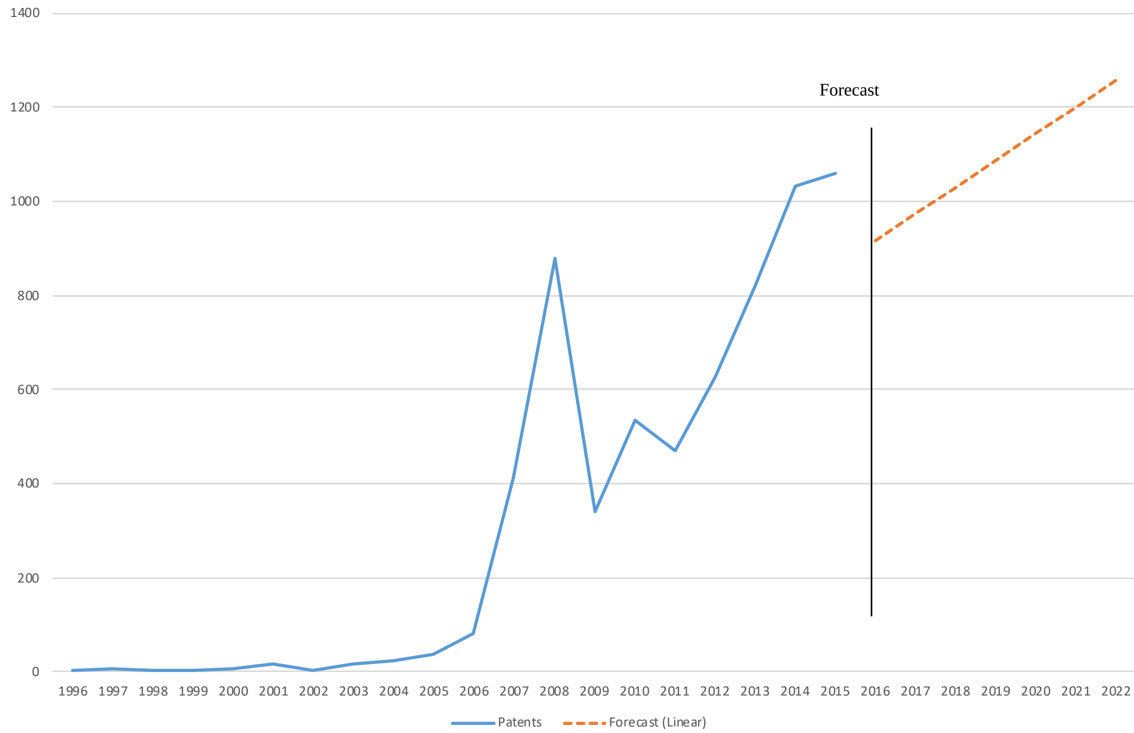

Figure 8 Military patents, China, linear forecast (2016-2022)

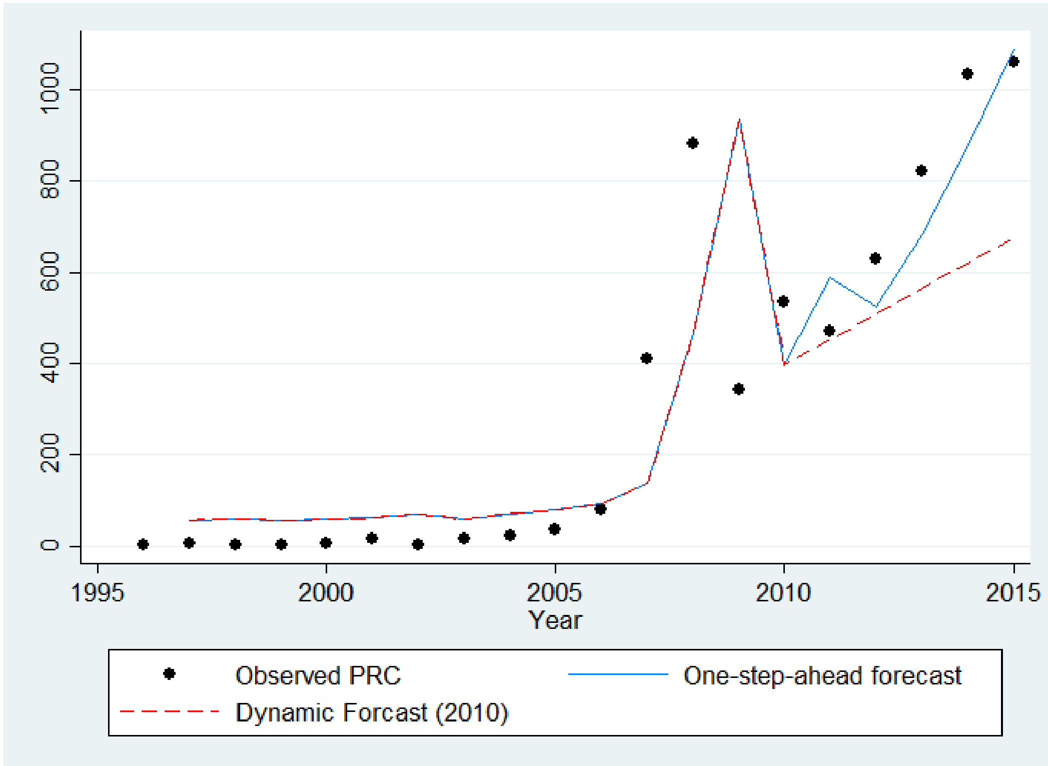

Figure 9 Military patents, China, ARIMA forecast (2010-2015)[86]

[86] To fit an ARIMA model, the data should be stationary. Figures 9 and 12 reveal the data to have a positive time trend (i.e. it is not stationary). For both the China and South Korea data series, taking a single difference makes the data stationary. Thus, I use a first order difference in the ARIMA model. Plotting the correlogram of the differenced series suggests that there is no need to include a moving average (MA) term. Plotting the partial correlogram of the differenced series suggests that there is no reason to include an autocorrelation (AR) parameter. Thus, for both the China and South Korea series a ARIAM (0,1,0) model is fit. Once the model it fit, the "predict" command in Stata allows for the generation of one-step-ahead forecasts and dynamic forecasts. For both series, I begin to generate dynamic forecasts at the year 2010. Thus, the plot below (and in Figure 12) include the observed values, the one-step-ahead forecasts, and dynamic forecasts beginning in 2010.

7.5 Sample 3: South Korean Military Technology Patents, 1996-2015

Table 31 Top 20 assignees, South Korea

Organization	Military Tech. Patents (1996-2015)	Organization Type
Agency Defense Dev	264	Government
LIG Nex1 Co Ltd	80	Firm
Samsung Thales Co Ltd	63	Firm
Samsung Techwin Co Ltd	30	Firm
Korea Elecom Co Ltd	22	Firm
Hyundai Rotem Co	20	Firm
Electronics & Telecom Res Inst	18	Government
Daewoo Electronics Co Ltd	15	Firm
Korea Aerospace Res Inst	15	Government
KAIST	13	Government
Korea Aerospace Ind Ltd	13	Firm
Samsung Electro-Mechanics Co	13	Firm
Hanwha Corp	12	Firm
Daewoo Shipbuilding & Marine Eng Co Ltd	11	Firm
GF Technology	11	Firm
Hyundai Motor Co Ltd	11	Firm
Poongsan Corp	11	Firm
Hyundai Wia Corp	10	Firm
Rotem Co	10	Firm
Elec Com Co Ltd	9	Firm

Table 32 Top 12 phrases, South Korea, (NLP applied to patent abstracts)

NLP Phrases Patent Abstract (ROK)	Patents
target	127
signal	125
image	101
vehicle	93
information	90
operation	81
sensor	76
battery	67
control unit	63
power	63
real-time	47
missile	46

Table 33 Top 10 IPC codes, South Korea

IPC (4-digit) Korea	IPC	Patents
F41A	Functional Features Or De	256
F41G	Weapon Sights; Aiming	236
F42B	Explosive Charges	177
F41H	Armour	167
F41J	Targets	155
G06F	Electric Digital Data Processing	113
G01S	Radio Direction-Finding	98
F42C	Ammunition Fuzes	74
F41F	Apparatus for Launching Projectiles or Missiles From Barrels	65
F41B	Weapons For Projecting Missiles	62

Table 34 Co-occurrence matrix, top 30 IPC codes, South Korea

Korea	F41A	F41G	F42B	F41H	F41J	G06F	G01S	F42C	F41F	F41B	H04B	H04L	B63G	H04N	G06Q	G09B	G08B	H02J	H01M	H01Q	G02B	G01C	G01R	H01L	H04W	G06K	G06T	B25J	H05K	G01N
F41A	***256***																													
F41G	74	***236***																												
F42B	14	29	***177***																											
F41H	12	8	21	***167***																										
F41J	60	35	8	8	***155***																									
G06F	20	19	5	5	11	***113***																								
G01S	6	11	8	21	5		***98***																							
F42C	3	3	23	1			3	***74***																						
F41F	13	14	24				1	3	***65***																					
F41B	4	5	8	3	1	1		1	5	***62***																				
H04B	3	9		1	1	1			1	6	***57***																			
H04L	2		2	3	1	7	1				6	***49***																		
B63G	5	2	14	15			2		5	3	1		***43***																	
H04N	2	4	1	2	1				1			1		***40***																
G06Q	4	2			1	7	2			1	2	1			***36***															
G09B	21	17	2		12	4						2	1	1	3	***36***														
G08B	3		1	3	2		3			4	3			2	1		***35***													
H02J	2	1			3					1	2				1			***35***												
H01M		1	1													1		4	***33***											
H01Q			1	1			2						1							***31***										
G02B	1	8		1		2	1				1			2							***27***									
G01C	3	7					2	1	1		1										1	***25***								
G01R	1	5	4	2	2				1		1					1	2	5	2				***24***							
H01L										1												1		***24***						
H04W			2				2	1			7	7			1								1		***24***					
G06K	2			1	1	3				1	1	1			5											***23***				
G06T		4		1	3									4												1	***22***			
B25J	1	1		3									1															***21***		
H05K				1		4								1															***21***	
G01N	4		1	3																			1				1			***20***

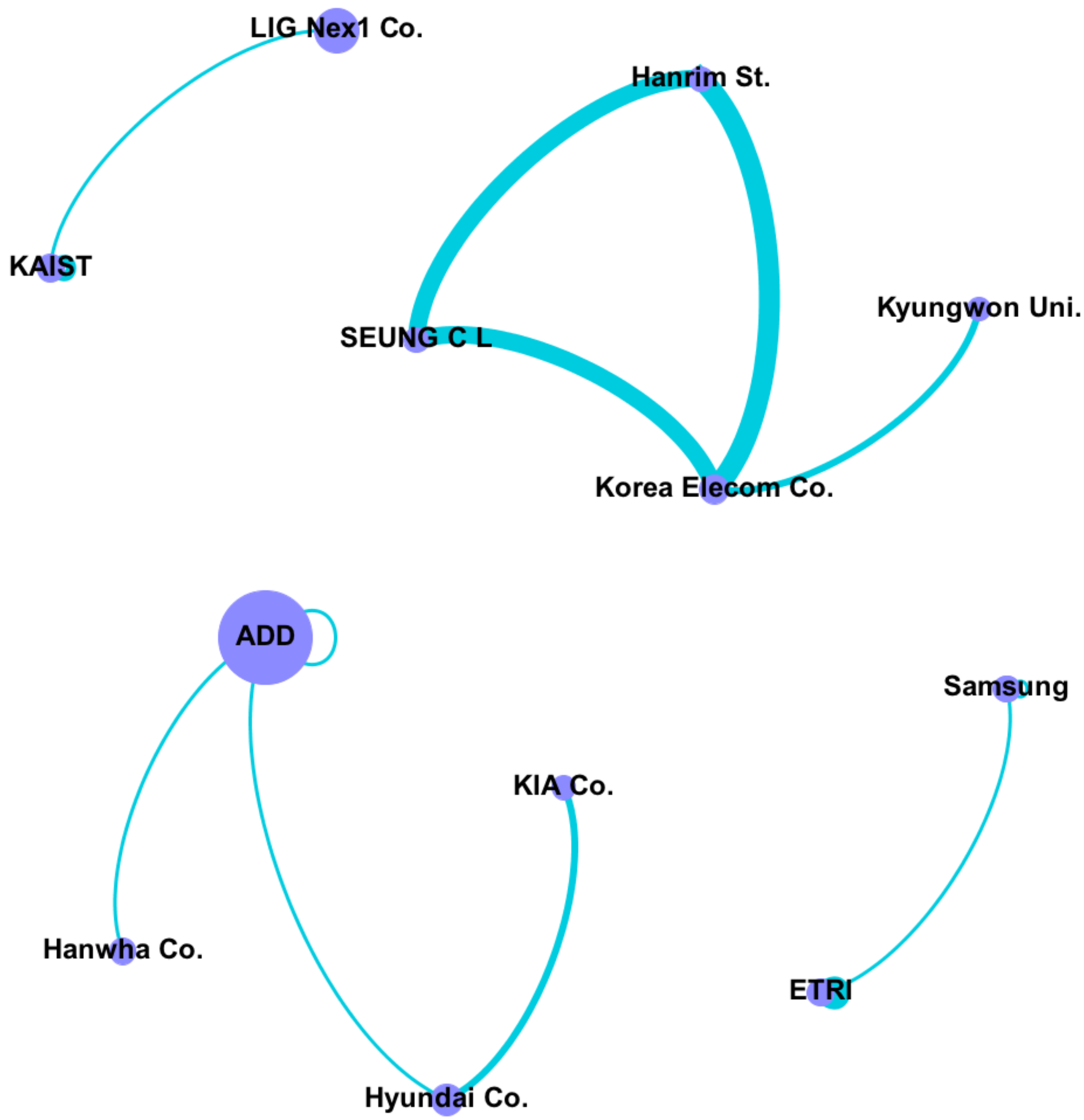

Figure 10 Collaboration network of top patent assignees, South Korea

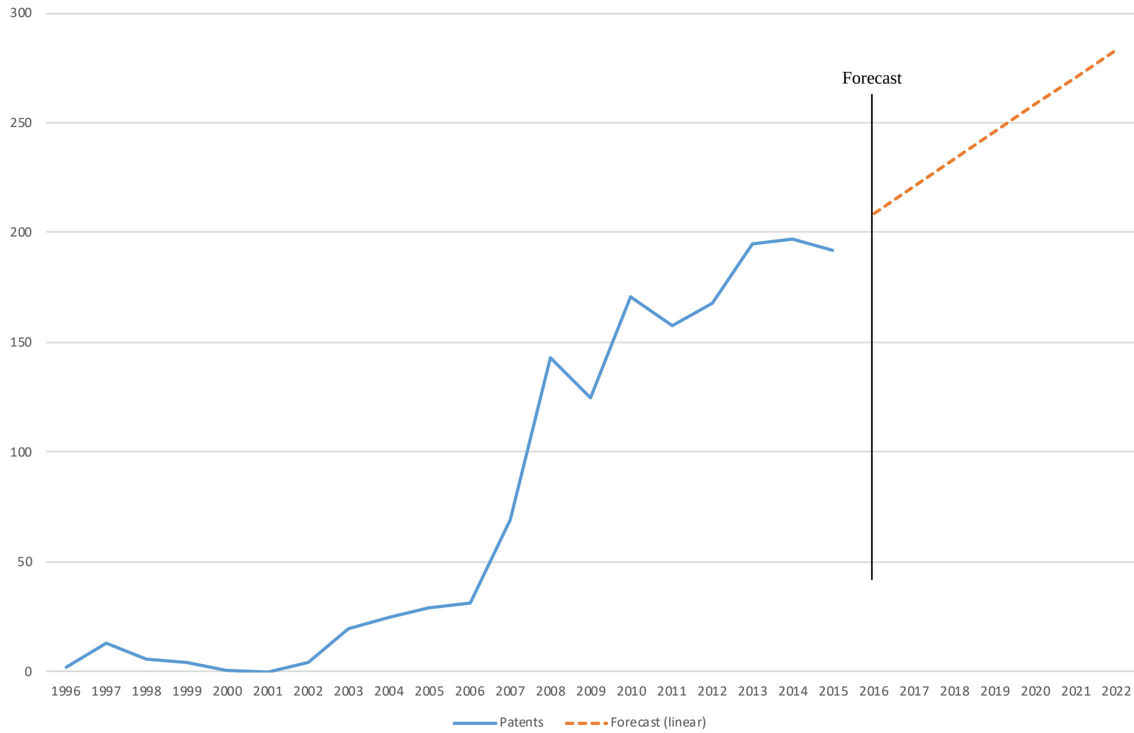

Figure 11 Military patents, South Korea, linear forecast (2016-2022)

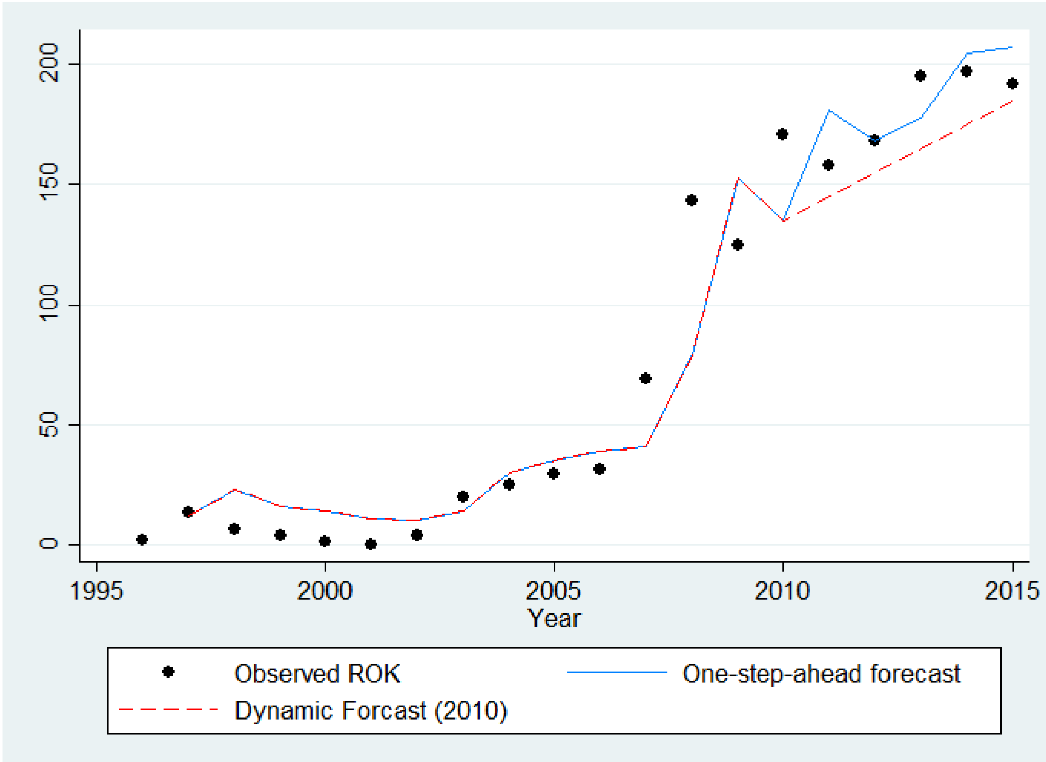

Figure 12 Military patents, South Korea, ARIMA forecast (2010-2015)

Table 35 Ranking of top five areas of technological focus (US/Israel congruence highlighted)

IPC (4-digit)	USA	China	Taiwan	ROK	Israel
Weapons Sight/ Aiming	#1	#1	#2	#1	#1
Radio Detection/ Finding	#2			#5	#2
Explosive Charges	#3	#2		#3	#3
Electrical digital data processing	#4				
Optical elements	#5				#5
Small arms and Ordnance			#5	#2	
Armor				#4	#4
Weapons for projecting missiles w/o explosives		#3	#1		
Pictorial communication		#4			
Ammunition Fuzes		#5			
Targets			#3		
Processes to convert chemical into electrical energy			#4		

The six graphs below compare the annual and cumulative patent output of the US, China, and South Korea for military technologies that contain some autonomous component. The data were gathered by searching the patent abstracts of each countries' military patents for the terms "autonomous" or "unmanned."[87] Patents containing either of the search terms were coded as being possessed of an autonomous component. A hand check of the results reveals that this approach produces very few false positives.

Such plots may be useful in placing a country's innovative output, at any given time, along a hypothetical S-shaped curve. Rogers (2003) finds that technology adoption frequently follows a predictable pattern. In particular, rates of adoption over time typically follow a bell-shaped curve. Cumulative adoption plots thus result in S-shaped or logistic curves. It is thus possible to compare a country's output for a given technology to this stylized fact in order to make judgements regarding its technological trajectory.

The plots below suggest that the US and South Korea appear to have reached a state of technological maturity in the development of autonomous military technologies. That is, for these countries, the rate of output of military patents that contain some autonomous component has decreased in recent years. China, in contrast, appears to remain on the ascendant portion of the technological trajectory.

[87] Other search terms could, of course, be used. The terms used here are merely meant to illustrate how it may be possible to hone in on a technological area that is outside of the formal classification schemes (IPC or Derwent Class Codes).

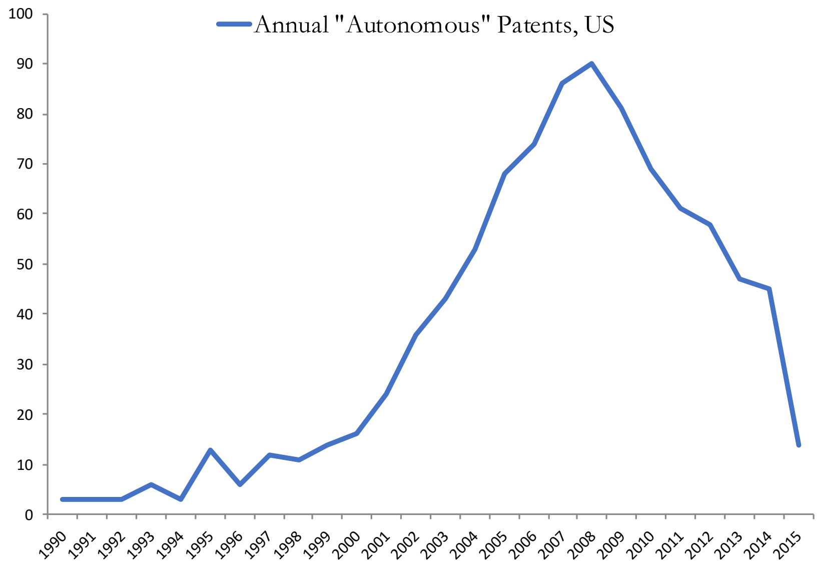

Figure 13 "Autonomous" military patents, 1990-2015, US[88]

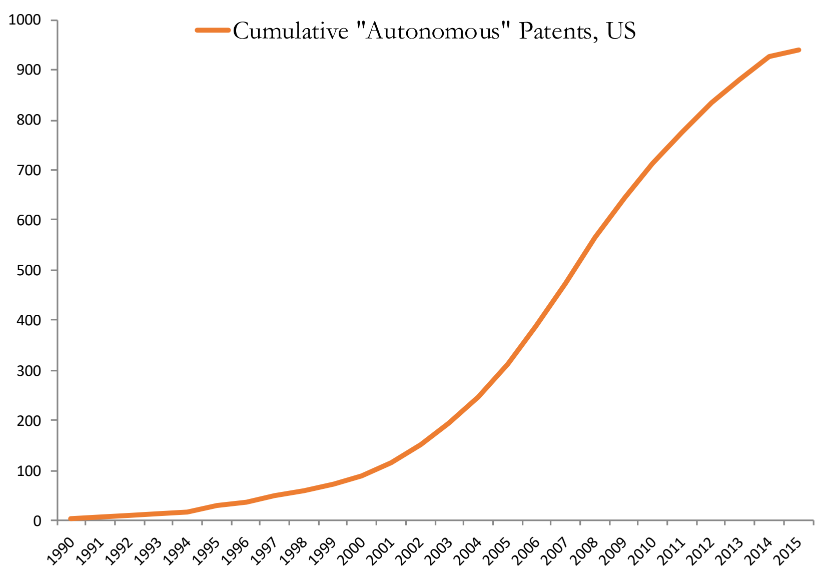

Figure 14 "Autonomous" military patents, 1990-2015, cumulative, US[89]

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88 Data refer to the annual number of military patents filed in the US that contain the terms "autonomous" or "unmanned" in the patent abstract.

89 Data refer to the cumulative number of military patents filed in the US that contain the terms "autonomous" or "unmanned" in the patent abstract. The deceleration of the S-curve indicates that military patenting for autonomous systems in the US has likely reached a stage of technological maturity.

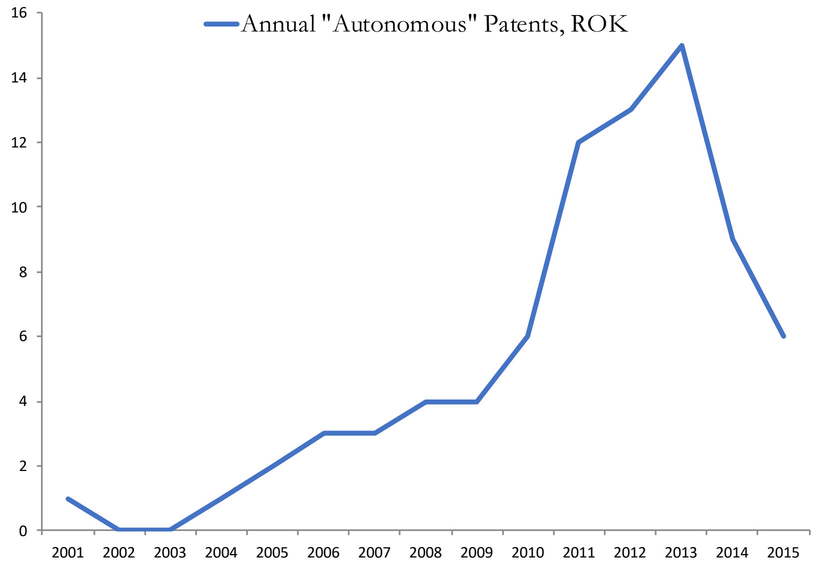

Figure 15 "Autonomous" military patents, 2001-2015, South Korea[90]

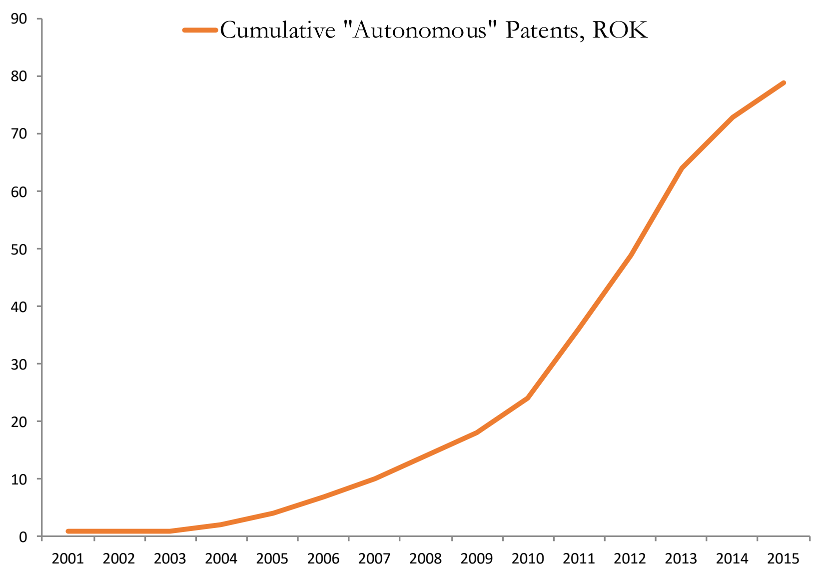

Figure 16 "Autonomous" military patents, 2001-2015, cumulative, South Korea[91]

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[90] Data refer to the annual number of military patents filed in South Korea that contain the terms "autonomous" or "unmanned" in the patent abstract.

[91] Data refer to the cumulative number of military patents filed in South Korea that contain the terms "autonomous" or "unmanned" in the patent abstract. In this case, the S-curve resembles that of the United States; South Korea appears to have reached maturity in this military technology field.

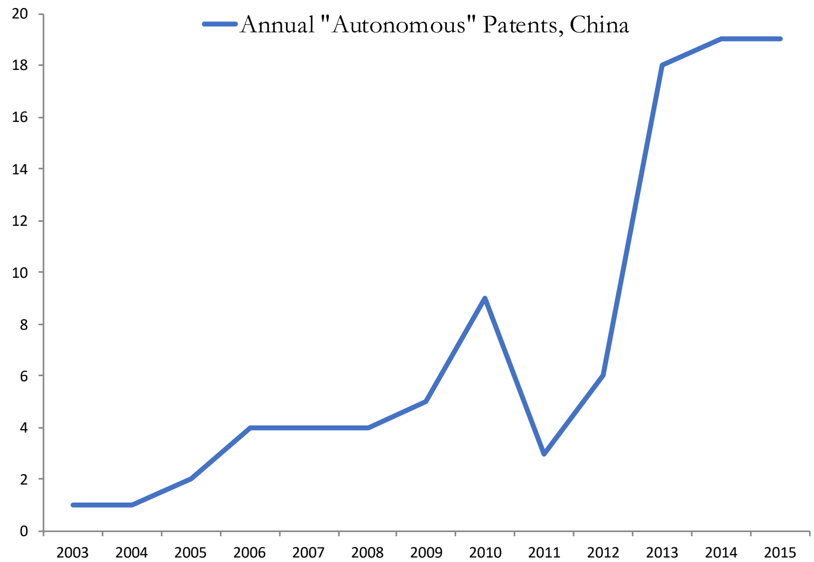

Figure 17 “Autonomous” military patents, 2003-2015, China[92]

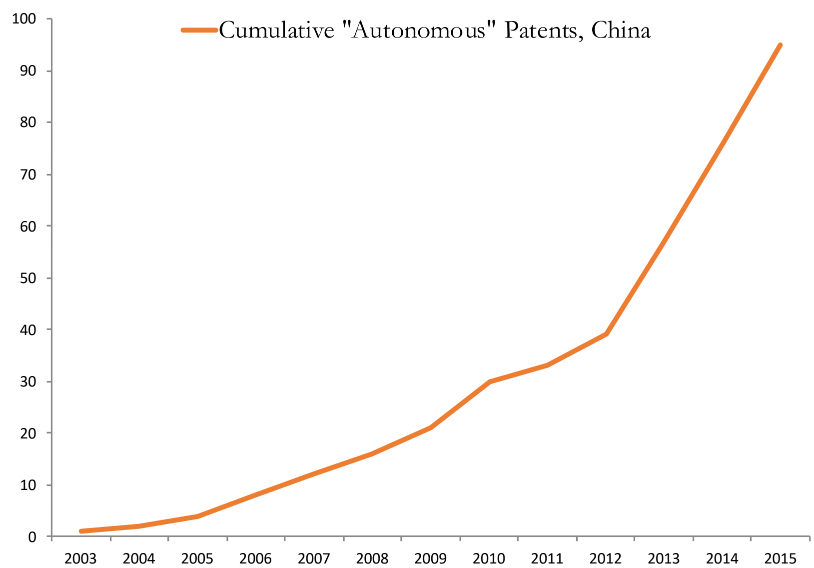

Figure 18 “Autonomous” military patents, 2003-2015, cumulative, China[93]

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[92] Data refer to the annual number of military patents filed in China that contain the terms “autonomous” or “unmanned” in the patent abstract.

[93] Data refer to the cumulative number of military patents filed in China that contain the terms “autonomous” or “unmanned” in the patent abstract. In this case, the S-curve appears to be in the exponential portion of the technology’s life cycle suggesting that military patenting for autonomous systems in China has not reached technological maturity.

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