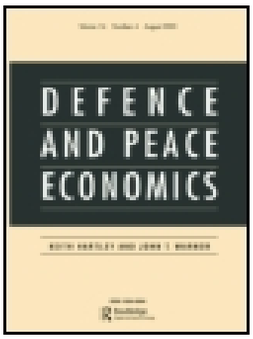

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Technological Emergence and Military Technology Innovation

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ABSTRACT

To what extent is military technology innovation emergent? This study answers this question by applying an emergence detection algorithm to roughly 300,000 technical terms extracted from military technology patents granted from 1980 to 2019. Emergence – instances of sudden and rapid growth of a technical term within the military patent corpus – is found to vary greatly over time. Military technology innovation during the period of 1996-2008 is found to be highly emergent. This period was found to be characterized by high organization-type diversity; non-traditional vendors, traditional defense contractors, large civilian-facing firms, and individuals generated military patents containing many novel emergent technical terms. However, in recent years, military technology innovation has exhibited markedly less emergence. The period of low emergence is characterized by reduced contributions by non-traditional vendors, defense prime contractors, and individual inventors to military patents containing emergent terms. These observations suggest that policies attempting to ensure a healthy defense innovation ecosystem should seek organization-type diversity and may benefit from employing promotion strategies targeted at distinct organization types.

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Defense innovation; military technology; defense industrial base; defense procurement

Introduction

Technological emergence refers to sudden and rapid growth of a coherent technology domain that has prominent impact (Carley et al. 2018). Whereas technological diffusion and adaption refer to processes whereby technologies are used by more entities, technological emergence refers to the process by which a new technology or technological domain initially comes into being (Daniele, Hicks, and Martin 2015). Empirically, technological domains exhibit inter-domain and inter-temporal heterogeneity with regard to the extent to which they exhibit emergence (Carley et al. 2018; Porter et al. 2019). A technological domain that exhibits a high degree of technological emergence will, by definition, produce a large number of technological 'emergences:' rapid and coherent technological offshoots that have significant practical impact. This study seeks to evaluate the attribute of technological emergence within the domain of military technology. Specifically, it seeks to answer the question: To what extent is military technology innovation emergent?

The answer to this question matters to scholars and policymakers. To military innovation and security scholars, understanding how the character and rate of military technological innovation varies over time is of relevance to debates about revolutions in military affairs (RMA) (Krepinevich 1992, Marshall 1993, Brose 2019) and the determinants of military innovation (Rosen 1994; Coté 1995; Sapolsky 1972, Posen 1984, Schmid 2018b). To policymakers aiming to ensure national military technology preeminence and cultivate a healthy defense innovation ecosystem, the organization-level sources of military technology emergence are of first-order concern.[1]

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This study answers this question by applying an emergent detection algorithm to roughly 300,000 technical terms extracted from military technology patents granted from 1980 to 2019. It then considers the organizations responsible for driving emergence (i.e. the organizations responsible for introducing novel technical terms into the military technology patent corpus) in effort to explain variation in emergence over time.

To preview the results, the study finds a high degree of variability in the extent of emergence over time. From 1996 to 2008, military technology innovation was found to be highly emergent. That is, relative to other periods analyzed, from 1996 to 2008 many more novel technical terms (e.g. detector array, unmanned vehicle, optical sight, piezoelectric element) appeared and exhibited continued rapid growth within the military technology patent time series data.

However, in recent periods, there has been a marked decline in the number of emergent terms introduced. Compared to the highly emergent 1996 to 2008 period, military technology patents from 2009 to 2019 contained less than 40% as many emergent terms. This finding – that of a substantial decline in emergence in recent years – holds both on an absolute and on a per patent basis.

To investigate potential explanations for this high variability over time, I examine the organizations responsible for introducing novel technical terms into the military patent corpus. The period of highest observed technological emergence (1999-2007) saw many distinct types of organizations (e.g. non-traditional vendors, universities, traditional defense contractors, large civilian-facing firms, and individuals) contribute patents containing new and fast-growing technical terms. Non-traditional defense contractors and individual inventors made particularly large contributions to emergence during this period. In contrast, during the most recent period analyzed – a period of low emergence –, non-traditional defense contractors and individual inventors made markedly decreased contributions to emergence. The importance of non-traditional defense contractors to emergence provides support for policy interventions that seek to broaden participation in the defense innovation ecosystem.[2] However, the role of individual inventors to defense innovation appears to be underappreciated; very little research or policy attention has focused on the topic. Additional investigation into the drivers, and possible inducements, of participation in the defense innovation system by individual inventors is warranted.

The study also finds that certain instances of emergence immediately preceded the onset of a novel security threat. For instance, a 2005 surge in patents containing the term 'improvised explosive device' triggered an emergence during the 1999–2005 analysis period. Looking at the technical content of these patents reveals them to protect intellectual property that was produced by U.S. firms to counter the burgeoning improvised explosive device (IED) threat in Iraq and Afghanistan during this period. This finding is relevant for explanatory models of state-level military technology innovation, which have largely focused on domestic factors such as intra-service rivalry, inter-service competition and civilian–military relations.

The remainder of this article proceeds as follows. The following section motivates the study; it presents three research and policy topics that will be informed the study's results. Section 3 describes the data and methodology, presenting the means by which military technology emergence is operationalized. Section 4 presents the results. The article concludes by considering how the results interact with existing scholarship and policy.

Motivation

The study of military technology emergence seeks to inform three policy and research topics. First, given the role of military technology as a deterrent of conflict and a variable that affects a belligerent's probability of victory in conflict, improved understanding of the character and drivers of military technology innovation will inform defense planners that seek to establish or maintain a net military technological advantage.[3] Second, by determining whether the military technology innovation process is punctuated by periods of rapid growth, this study will inform revolutions in

military affairs (RMA) scholarship. Third, this study will inform, although not test, the long-standing academic debate on the determinants of military technology innovation. The remainder of this section elaborates these policy and research topics, placing them in context of the empirical investigation to follow.

Military Technology and the Defense Innovation Ecosystem

Net military technological advantage affects the outcome of armed conflict, improves a state's capacity to project power, and serves to deter aggression by would-be adversaries. Thucydides describes how the Boethians used proto-flamethrowers to burn and destroy Delium fortifications during the Battle of Delium (424 BC) of the Peloponnesian War. In the battles of Laupen (1339) and Crecy (1346), English archers used the six-foot yew longbow, and novel infantry tactics, to prevail (Krepinevich 1994). Venetian victory over Turkish forces during the Battle of Preveza (1538) was assured by using sailing-ship mounted cannons, which were able to easily sink oar-powered Turkish galleys (Krepinevich 1994). More recently, overwhelming U.S. victory in the 1990–1991 Gulf War was, in part, enabled by precision-guided munitions such as AGM-130 'smart bombs' and the communication and targeting support provided by early warning aircraft such as the E-2 Hawkeye and the E-3B Sentry. The decisiveness of the U.S. victory in Operation Desert Storm – with ratios of Iraqi to U.S. troop and platform losses approaching one thousand to one – has also been argued to have had a deterrence effect, dissuading states from engaging in conventional battle with the United States (Perry 1991).

Little is known about the particular conditions that promote a healthy defense innovation ecosystem. The defense sector has idiosyncratic features that may prevent the generalization of policy approaches drawn from the study of commercial sectors. For one, the defense sector is, for the most part, a monopsony. The effect of serving a single buyer on innovation, is that the technical character of a firm's innovation is largely determined by the government via detailed technical requirements rather that via market mechanisms (Alic et al. 1992; Bellais and Guichard 2006).

Operating in the defense sector also requires that firms adhere to a complex and stringent set of rules regarding accounting, cost accounting and allotment, and financial disclosure. These requirements crate a barrier to firm entry and give existing defense market participants an incumbency advantage that limits firm exit (Dombrowski and Gholz 2006). A static firm ecosystem may affect innovation by limiting competition and preventing the entry of new firms, especially startups, which have been shown to introduce a high proportion of innovation into the sectors in which they operate (Czarnitzki and Delanote 2013; Homfeldt, Rese, and Simon 2019).

Given the importance of technological superiority, and its likely particular consequence in a contemporary security environment characterized by strategic competition between large technologically sophisticated states (Gilli and Gilli 2019), it is not surprising that U.S. military planners seek to ensure that U.S. forces remains at a technological advantage. The 2022 DoD budget request includes a $112 billion research, development, test and evaluation (RDT&E) request, the largest ever made ("The Department of Defense Releases the President's Fiscal Year 2022 Defense budget" 2021). The recent creation of myriad innovation-focused organization including Defense Innovation Unit, National Security Innovation Network, Army Futures Command, DEFENSEWERX, and AFWERX suggest that the US Office of Secretary of Defense (OSD) and individual military service branches also value continued U.S. military tech dominance. This study hopes to inform the process of promoting military technology innovation by identifying periods of high military technology emergence and the organizations responsible for driving military technology emergence. By informing policymakers about the particular organizations and mix of actor types (e.g. individuals, government research labs, large defense contractors, dual-use firms, and non-traditional vendors), this study will inform the policy objective of promoting military innovation. The policy implications of the study's findings for defense innovation promotion are elaborated in Section 5.1.

Revolutions in Military Affairs

Revolutions in military affairs (RMA) refer to periodic surges in military technology innovation – accompanied by concurrent innovation in doctrine, concepts of operation, and organizational structure – that yield a dramatic improvement in military effectiveness (Krepinevich 1992). The notion an RMA traces to Soviet military theory in the 1970s. Soviet theorists hypothesized that integrating new technologies such as wide-area sensors, airborne synthetic aperture radar, and laser guidance systems onto conventional weapons would result in a dramatic increase in military effectiveness, a military-technology revolution (MTR).

The center of the MTR concept into U.S. military thought owes largely to the Office of Net Assessment (ONA) during the leadership of Andrew Marshall. Marshall along with the ONA's Andrew Krepinevich studied the writings of Soviet thinkers and concurred with claims of a pending technology-induced discontinuity in military effectiveness but broadened the notion of MTR to include coincident doctrinal and organizational innovation (Krepinevich 1992; Marshall 1993). Marshall succinctly characterizes the necessary, yet insufficient, contribution of technology to precipitating a RMA, stating, 'Technology makes possible the revolution but the revolution itself takes place only when new concepts of operation develop and, in many cases, new military organizations are created' (Marshall 1994, 1).

Embedded in the notion of RMA is a hypothesis about the character of military technological change. An RMA-oriented perspective understands military technological change as revolutionary: characterized by technological discontinuity and periods of radical change. In the language of innovation scholarship, during an RMA, military technology innovation exhibits *emergence*: rapid growth in coherent technology areas that have prominent impact (Carley et al. 2018). Existing scholarship on RMA tends to debate whether a given period constitutes a legitimate instance of RMA (see, for example, Brose 2019). However, whether a series of periodic revolutions is an appropriate general characterization of the relationship between military technology innovation and time has yet to be tested. This study proposes to test the RMA's hypothesis of military technological change empirically. The implications of the study's results for the RMA hypothesis are elaborated in Section 5.3.

Theories of Military Innovation

This study also seeks to inform the long-standing debate about what causes military innovation. Most existing theories on the determinants of military innovation focus on domestic variables. Prominent theories of military innovation locate the impetus for innovation on intra-service rivalry (Rosen 1994), inter-service competition (Coté 1995; Sapolsky 1972), and civilian-military relations (Posen 1984). The potential causal role of external security threats in driving military change has received scant attention. In fact, Grissom contents that theories of military innovation based on external threats have been 'rejected by the field' (Grissom 2006, 908).

Recent scholarship, however, has found evidence that changes in the international security environment may in fact drive technology change. This research finds a correlation between a country's threat environment and its overall innovation output (Schmid and Huang 2017; Taylor 2004, 2016; Schmid, Brummer, and Zachary Taylor 2017; Brummer 2020) and its military technology output (Schmid 2018a). In the analysis to follow, additional evidence that threats matter in military innovation are provided. I show, in Section 5.4, that the onset of two new external military threats immediately preceded two instances of military technology emergence for relevant counter-threat technologies.

Data and Methods

To investigate military technology emergence, I apply an emergence detection algorithm to a set of over 300,000 terms (e.g. 'night vision') extracted from a purpose-built dataset of over 19,000 military technology patents. Terms are extracted from patent titles and patent abstracts primarily using

natural language processing (NLP) techniques. Each term is evaluated for adherence to a set of emergence criterion. The number of emergent terms for a given period is used as a measure of the extent of military technology emergence during that period. Each of these steps is described in detail below.

Data

The patent data used here come from the Derwent Innovation Index (DII). The DII is a database containing patent grant data from of over 50 distinct patent-granting judications, including all major country-specific and multi-country patent organizations. To define military patents, I use the Derwent Class Code W07 (Electrical Military Equipment and Weapons).

The case for the use of military patents as a reasonable measure of military technology innovation proceeds by demonstrating that military patents, as a metric, conform to a commonsense scholarly definition of military technology (Schmid, Brummer, and Taylor 2017; Schmid 2018a, Schmid 2018b). Stephen Peter Rosen defines military technology innovation as, 'the process by which new weapons and military systems are created' (1991, 185). He then proposes that military technology innovation 'is the business of military research and development (R&D) communities' (1991, 185). To adhere to Rosen's definition, a good measure of military technology innovation should therefore consist of *military* technologies and be generated by military R&D communities. With regard to the former, the patents within the W07 Derwent Classification are designated by subject matter experts at Derwent as belonging to the Electrical Military Equipment and Weapons classification. With regard to the latter, Table 1 indicates that the patent dataset used here is comprised of patents developed by members of the U.S. military R&D community; namely, the table has substantial overlap with the organizations considered in the military technology innovation literature (Manuel et al. 2018; Alic 2007; Dombrowski and Gholz 2006).

This is not to say that patents are a comprehensive proxy of military technology innovation. Much of military technology innovation is held by organizations as trade secrets. Such innovations simply do not show up in the global corpus of patent documents. Instead, this study claims something more modest: that military patents constitute a rich data source that offer scholars means to better understand the trends and technical character of a country's defense innovation output.

The analysis to follow spans the period 1980–2019.[4] Over this period, there were 19,187 military patents granted. These patents constitute the dataset compiled for this study. For each patent (i.e. each observation), the patent's 'front page' information is collected. 'Front page' information includes data fields such as priority date, patent assignee, inventor, patent title, patent abstract, international patent classification codes, and Derwent Class Codes. In the analysis to follow, patents are assigned a year using their priority year: the first filing date of the patent. The dataset is limited to patents for which the priority filing was made at the United States Patent and Trademark Office (USPTO).[5]

Table 1. Top military patent assignees, 1980-2019.

Organization	Military Patents (1980-2019)
US Navy	1044
Raytheon	1042
US Army	792
Boeing	677
Lockheed Martin	585
Honeywell	498
Hughes Aircraft	333
BAE Systems	297
Northrop Grumman	225
US Air Force	209

Operationalizing Technological Emergence

In the analysis to follow, technological emergence is operationalized following the method proposed by Carley et al. (2018). VantagePoint, a text mining software, is used to implement Carley et al.'s (2018) emergence detection algorithm. The approach was designed to adhere to the definition of emergence advanced by the Foresight and Understanding from Scientific Exposition (FUSE) Program run by the Intelligence Advanced Research Projects Activity (IARPA). The FUSE Program introduced four emergence criteria: novelty, persistence, community, and growth. To operationalize emergence for military technology, these criteria are applied to a time series of candidate terms that were extracted from patent titles and patent abstracts via NLP. Terms that conform to the emergence criteria described below are deemed emergent terms and an indicator of military technology emergence during the period under analysis.

To arrive at a set of candidate terms, I apply an NLP term-extraction algorithm to the patent titles and patent abstracts of the 1980–2019 military patent dataset.[6] This produces a list of over 350,000 distinct terms or phrases. Once common English-language stopwords and patent-specific stopwords were removed from the list, a thesaurus was applied to convert instances of British spelling into American English spelling (e.g. Fibre was replaced with Fiber). Finally, a fuzzy-matching algorithm was applied to the list to combine terms based on stemming differences (e.g. 'machine gun' and 'machine guns' were combined into a single term: 'machine gun'). The cleaning process results in a list of roughly 300,000 distinct terms or phrases to be investigated for emergence.

Relying on terms extracted from patent text, instead of on existing patent classification codes to determine the technical content of a patent, allows the methodology to identify new technical areas that have yet to be incorporated as official patent classifications. This is a particularly valuable feature of an emergence detection methodology, as emergences, by definition, are new phenomena and therefore likely to precede the creation of a new patent classification code.

Emergence is a quality that depends on the time trend of an underlying phenomenon. To search for emergence during a given period, the full forty-year (1980–2019) data series is split into 39 distinct 10-year periods (e.g. 1980–1989, 1981-1990 . . .). For any given 10-year period, the first three years are defined as the base period and the final seven years are defined as the analysis period.

For each of the 39 10-year periods, all 300,000 candidate terms are assessed with respect to adherence to the FUSE Program's four emergence criteria. First, for a term to be classified as emergent it must cross three threshold criteria:

- *Novelty* – to be classified as emergent, a candidate term must appear in fewer than 15% of the patents in the baseline period (i.e. the first three years of each ten-year period) and in twice as many patents during the active period (i.e. the seven years following the baseline period) as the baseline period.
- *Persistence* – to be classified as emergent, a candidate term must appear in patents from at least three years of the analysis period and in seven distinct patents.
- *Community* – to be classified as emergent, a candidate term must appear on the patents of an assignee (i.e. the patent owner) that does not co-patent on the same set of patents. That is, the patents in question must not belong to a single community, where community is defined as assignees that are linked by co-patenting on the same patents.

Once these three threshold criteria are met, an emergence score is calculated based on the *Growth* of the term during the analysis period. The emergence score is calculated as a linear combination of three growth trends during the analysis period.[7] In the analysis to follow, emergence scores above 1.77 are classified as emergent.[8]

Adherence to the emergence criteria is perhaps best illustrated by example. The term 'night vision' was found to be emergent during the period 1980–1989. During the three-year base period (1980-1982), the term 'night vision' appeared in just two patents. During the active period, the term

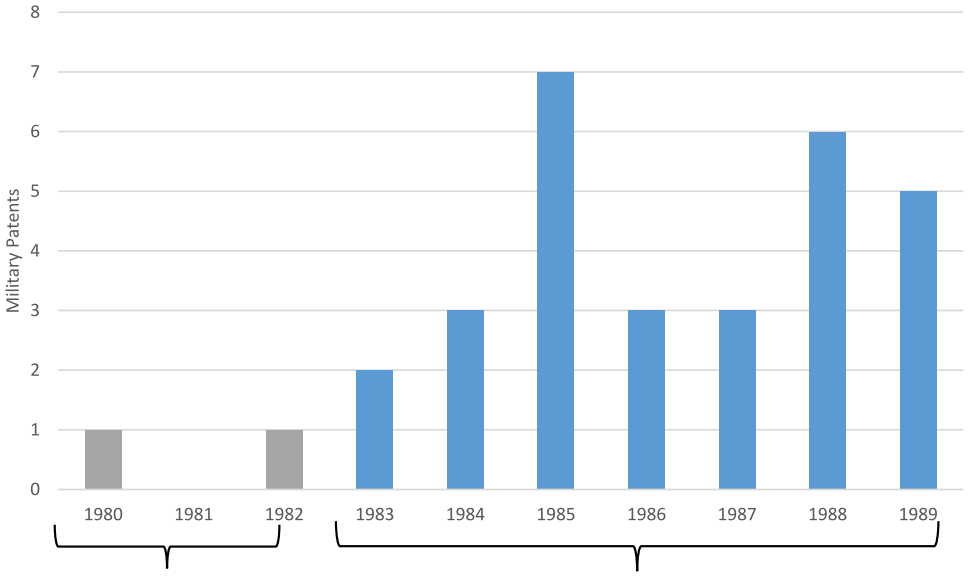

Figure 1. Occurrence of the term 'night vision' in military patents, 1980-1989.

'night vision' appeared in 29 patents. The novelty criteria requires that the term appear in fewer than 15% of the baseline period patents and more than twice as many patents during the active period as the baseline period. In this case, both conditions are easily met. Figure 1 depicts the time trend of the term 'night vision' as it appears in the military patent dataset during the 1980–1989 period of analysis.

Meeting the persistence requirement requires that an emergent term appear in at least three years during the analysis period. The term 'night vision' appears in all seven of the analysis period years (1983–1989) and thus satisfies the persistence criteria.

Finally, for a candidate term to meet the community criteria, it must appear on the patents of assignees that do not co-patent together. In the case of the military patents containing the phrase 'night vision,' there is little co-patenting. Boeing and Textron System (patent number US5335060) are co-listed on one of the 31 'night vision' military patents during the period and the rest of the patent assignees are sole-assignees. Therefore 'night vision' meets the community criteria.

Once a term is found to be emergent, it is possible to determine which individuals and organizations are responsible for developing the patents containing emergent terms. In the analysis to follow, the patent assignees (i.e. patent owners) of patents containing emergent terms in the patent title or abstract are called emergent assignees. In the analysis to follow, I follow the method proposed in Carley et al. (2018) and calculate an organization's emergence score as the sum of the square roots of the emergence scores for all of the organization's patents that contained an emergent term during the period of analysis.

Results

To What Extent is Military Technology Emergent?

Analysis of military technology patents from 1980 to 2019 finds a high degree of variability in the number of emergent terms detected. During the 1982-1991 and 1983-1992 periods only 21 emergent terms were detected. During the 1998-2007 period, 157 emergent terms were detected,

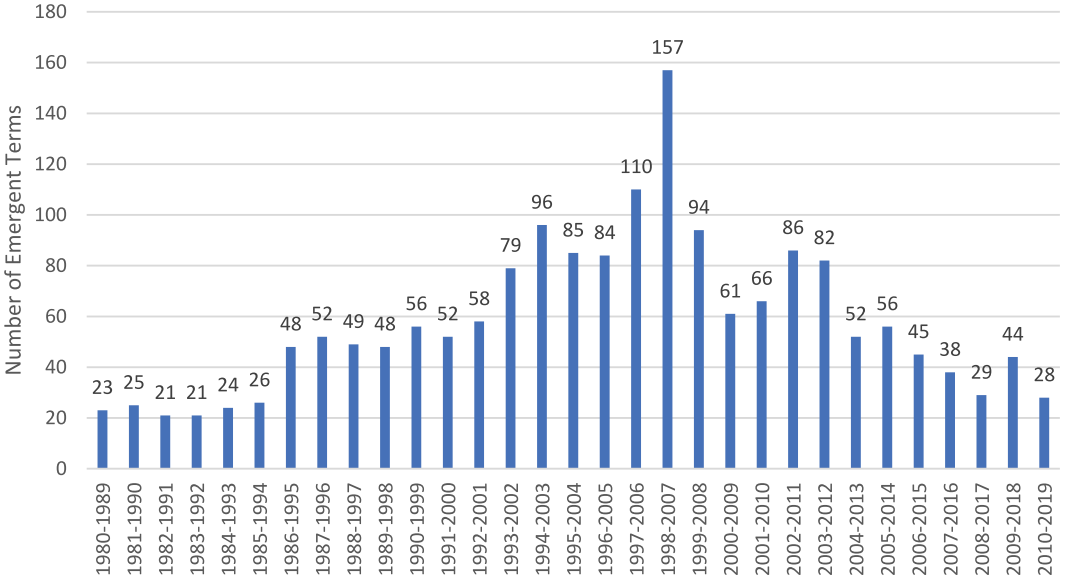

Figure 2. Military technology emergence, 1980-2019.

substantially more than any other period. The mean number of emergent terms detected during the 31 seven-year periods considered is 58. Figure 2 depicts the depicts the number of emergent terms detected in each of the 31 periods analyzed.

In addition to the high observed variability, emergence analysis of military technology patenting from 1980 to 2019 yields at least two insights regarding temporal trends. First, the mid 1990s to the end of the 2000s, was a period of high emergence in military technology. The period of high emergence begins in the 1996-2002 analysis period (this period uses the base period of 1993-1995, so appears in Figure 2 as 1993-2002) and spans until the 2001-2008 analysis period. During this set of seven 10-year periods, there were an average of 101 emergent terms.

Second, in recent periods there has been a marked decline in the number of emergent terms detected. On average during the five most recent seven-year periods analyzed (spanning an analysis period of 2009-2019) only 37 emergent terms were detected.

The low emergence characterizing more recent periods is not a function of decreased overall military patenting. Dividing the number of emergent terms in a period by the total number of military patents during the period, gives a measure of emergence that is normalized for patenting levels. Figure 3 displays the number of emergent terms detected during each period as a fraction of the total number of military patents granted during the period of analysis. The figure indicates that the observed decline in emergence terms detected in recent periods is evident even after accounting for overall military patenting levels. On a per patent basis, recent patents contain fewer emergent terms that those in previous periods.

Which Organizations Drove Emergence?

To investigate whether there have been changes to the types of organization that have driven military technology emergence, this section considers the contribution of particular organizations to emergence in three time periods: 1980-1989, 1998-2007, and 2010-2019. The first period is characterized by a relatively low level of emergence that was driven by the traditional defense industrial base organizations. The second period is characterized by high emergence driven by substantial diversity in terms of organization types. The most recent period is

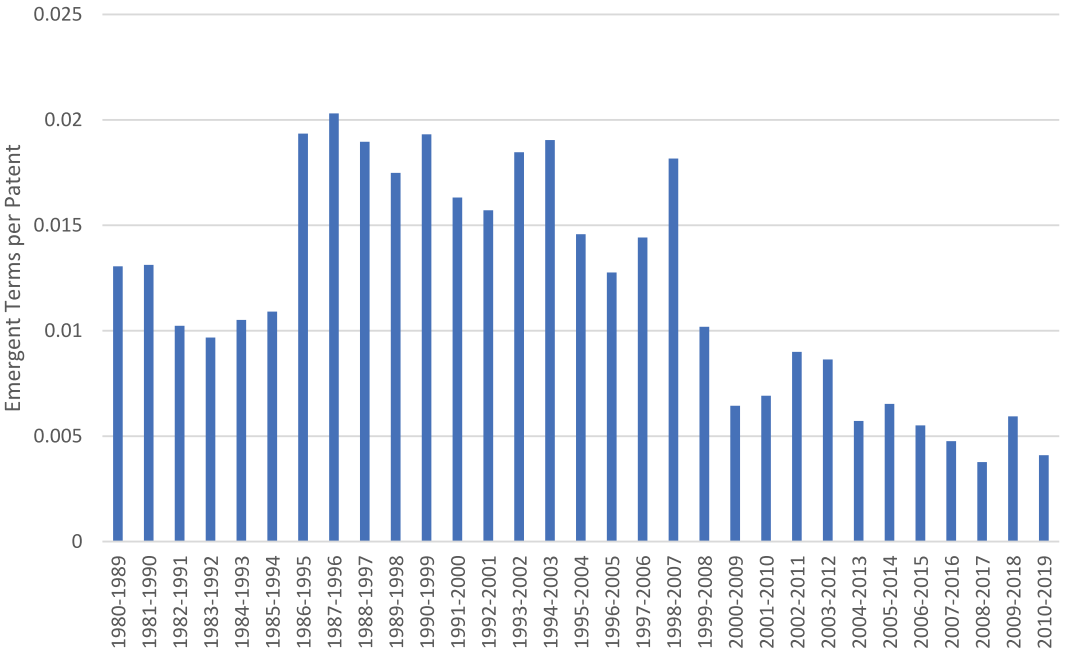

Figure 3. Emergent terms per patent, 1980-2019.

characterized by low emergence. During the most recent period, there is a substantial decrease in the contribution of individual inventors and large defense primes to military patents containing emergent terms. The remainder of this section considers each of these periods in greater detail, focusing on the changing role of different types of organization to emergent terms in military technology patenting.

1980-1989

During the 1980-1989 period, application of the emergence detection criteria to the military patent dataset yielded just 23 emergent terms, the third lowest in the 39 periods analyzed. The top five emergent terms (in terms of emergence score) during this period were optical fiber, electrical current, filament, firing mechanism, and laser radiation.

Table 2 contains the top 10 organizations based on emergence score for the 1980-1989 period and the total number of military patents granted to each organization. In total during the 1980-1989 period, there were 27 unique assignees granted patents containing at least one of the emergent terms. None of these were individuals. The organizations that drove emergence (i.e. the organizations that were granted patents containing terms that were found to be emergent during the 1980-1989 period) were largely traditional defense contractors and military service branch-based laboratories.[9]

Figure 4 plots organization-level emergence scores against the number of military patents granted to that organization during the 1980-1989 period for the emergent patent assignees for the period (i.e. all organization to have been granted at least one patent containing an emergent term in the patent title or abstract). The plot shows that the organizations with the highest emergence scores during this period are large defense-contractors and government research laboratories.

Table 2. Top 10 organizations by emergence score, 1980-1989.

Organization	Emergence Score (1980-1989)	Military Patents (1980-1989)
Boeing	13.6	76
Hughes Aircraft	9.9	96
US Army	7.9	248
Joanell Lab	7.9	8
Litton Systems	4.2	9
Allied-Signal	3.9	9
US Navy	3.3	178
Varo Inc.	3.3	17
United Technologies	3.3	14
US Air Force	3.2	75

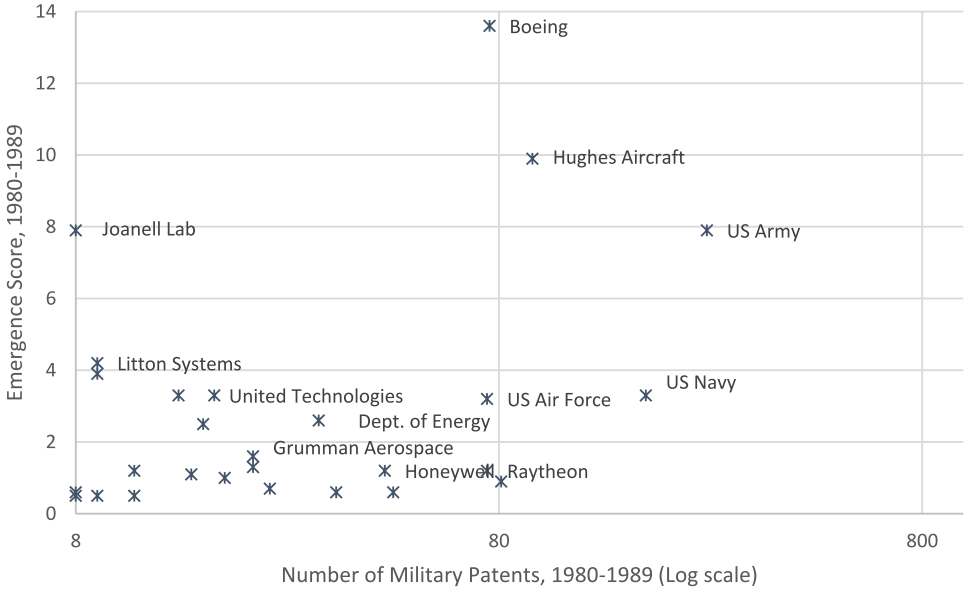

Figure 4. Emergence score vs. number of military patents by assignee, 1980-1989.

1998-2007

During the 1998-2007 period, there were 157 unique emergent terms: substantially more than any other period. On a per patent basis, the 1998-2007 period was the seventh most emergent period. The top five emergent terms during this period were communication system, computer-readable medium, electronic device, biological agents, and explosives. Table 3 ontains the top 10 organizations based on emergence score for the 1998-2007 period.

Table 3. Top 10 organizations by emergence score, 1998-2007.

Organization	Emergence Score (1998-2007)	Military Patents (1998-2007)
Morpho Detection	28.4	11
Omnitek Partners	22.2	36
General Electric	18.9	36
Rapiscan Systems	18.5	8
Boeing	16.8	296
Harris Corp	16.2	50
Raytheon	13.5	405
I-Robot	13.4	25
Lockheed Martin Corp	13.1	347
Honeywell	12.3	247

Analysis of the organizations responsible for the highly emergent 1998-2007 period reveals four intriguing observations. First, many of organizations that drove emergence were non-traditional vendors. While these firms did not contribute as many military patents as traditional defense contractors, they made outsized contributions to the high number of emergent terms detected during the period. In fact, the three of the top four organizations in terms of emergence score (Morpho Detection, Omnitek Partners, and Rapiscan Systems) were non-traditional vendors. These organizations produced 55 military patents during the period compared to the 802 military patents produced by the top three traditional defense contractors (Raytheon, Lockheed Martin, and Harris Corporation). However, the average emergence scores of these three organizations (measured as the sum of the square roots of the emergence scores for all the organization's patents containing an emergent term) was higher (23.0) than that of the traditional contractors (14.2).

During the 1998-2007 period, the top-ranking organization, based on emergence score, was Morpho Detection, which was a subsidiary of the SAFRAN Group and the General Electric Company. Emergent terms to which Morpho Detection contributed include X-rays, concealed weapons, contraband, cargo container, inspection system, and non-invasive. Omnitek Partners was the second highest ranking organization and is a relatively small military-servicing firm that specializes in components such as inertial igniters, actuation devices, and various types of sensors. Emergent terms to which Omnitek Partners contributed include thermal battery, external batteries, small rocket, energetic material, piezoelectric element, and electrical energy. The fourth highest ranking organization was Rapiscan Systems, a privately held company based in Torrance, California that specializes in X-ray threat detection systems. Emergent terms to which Rapiscan Systems contributed include cargo container, delivery vehicle, energetic material, toxins, airport, inspection system, contraband, and detector array.

Another notable observation is that traditional defense-servicing firms and defense-focused government research organizations continued to play an important role in producing emergent technology during this period. Large defense contractors such as Raytheon, Lockheed Martin, Harris Corporation, and Honeywell contributed substantially to military patents containing emergent terms during the 1998-2007 period. The government research organizations associated with the US Navy and US Army also had high emergence scores during this period.[10]

Third, a set of large civilian-facing firms including General Electric, IBM, and Boeing, are amongst the top contributors to the highly emergent 1998-2007 period. Finally, the role of individuals as patent assignees during the highly emergent 1998-2007 period is noteworthy. During the 1998-2007 period, 11 of the 102 (10.6%) assignees to have produced a military patent containing an emergent term were individuals. The average emergence score of an individual during this period was 12.9 compared to 4.7 for all other assignees. Figure 5 depicts the emergence scores vs. the total military patents produced by the organization during the highly emergent 1998-2007 period.

2010-2019

During the 2010-2019 period, applying the emergence detection criteria to the military patent dataset yielded just 28 emergent terms. On a per patent basis, the 2010-2019 period was the second least emergent period of the 39 periods analyzed. The top five emergent terms during this period were autonomous vehicle, wearable device, electronic scope, impact location, and viewing optic. Table 4contains the top 10 organizations based on emergence score for the 2010-2019 period.

Individual inventors played a reduced role in driving emergence during the most recent period. During the 2010-2019 period, only two of the 41 (4.9%) assignees to have produced a military patent containing at least one emergent term were individuals. During the highly emergent 1999-2007 period, 11 of the 102 (10.6%) emergent assignees were individual inventors. Figure 6 depicts the plot of the emergence scores against the total military patent produced by the organization in question for the most recent period analyzed.

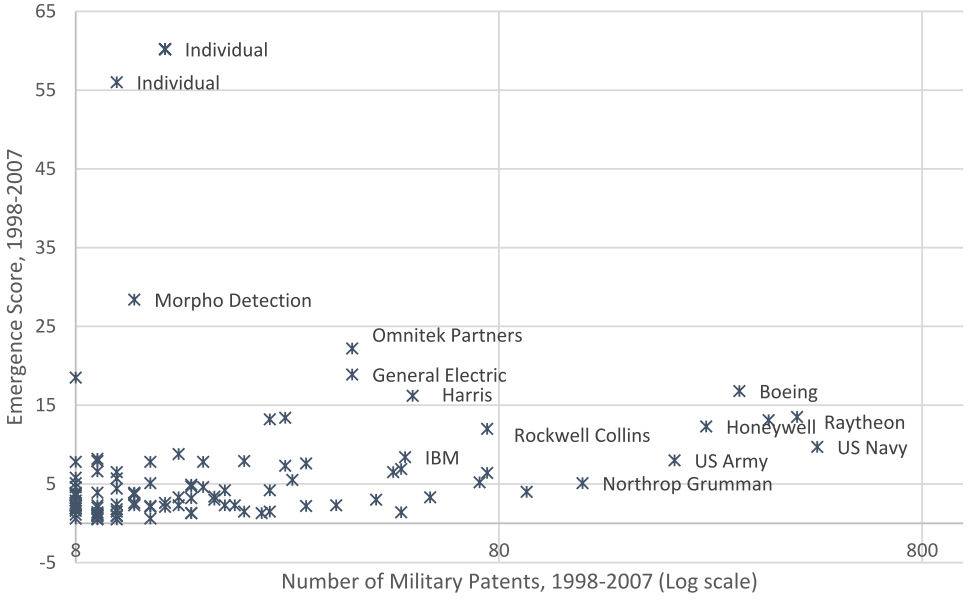

Figure 5. Emergence score vs. number of military patents by assignee, 1998-2007.

Table 4. Top 10 organizations by emergence score, 2010-2019.

Organization	Emergence Score (2010-2019)	Military Patents (2010-2019)
Sheltered Wings	9	12
Dana Heavy Vehicle	5.3	16
Brain Corp	4.5	15
Digital Global Systems	3.9	9
Facebook	3.2	10
Axon Enterprise	2.7	37
Omnitek Partners	1.9	61
Grace Engineering	1.7	9
Denso	1.4	40
Oshkosh Defense	1.4	9

Limitations

At least two limitations of this study are worth highlighting. First, as noted in Section 3.1, patent data are an incomplete measure of military technology innovation. Much military technology innovation is maintained as trade secrets and this innovation is simply unaccounted for in this study.

Second, this study focuses on the military technology innovation output of a single country: the United States. While considering a reasonably long period of military patents allowed for comparing the rate at which new technical terms were introduced into the corpus of US military patents over different periods, the methodology employed here does not allow for cross-case comparison. Extending the analysis to additional countries would allow for comparison of competitors (e.g. the U.S. vs. China). Additionally, considering additional cases may provide insight into the character of country-level patterns of military technology diffusion, a topic of recent scholarly attention (Michael, Schwartz, and Fuhrmann 2022; Early et al. 2022).

Implications of Results

Section 2 defined three factors that motivated this research. The results have provided insight into each of these policy and research areas. This section elaborates these insights.

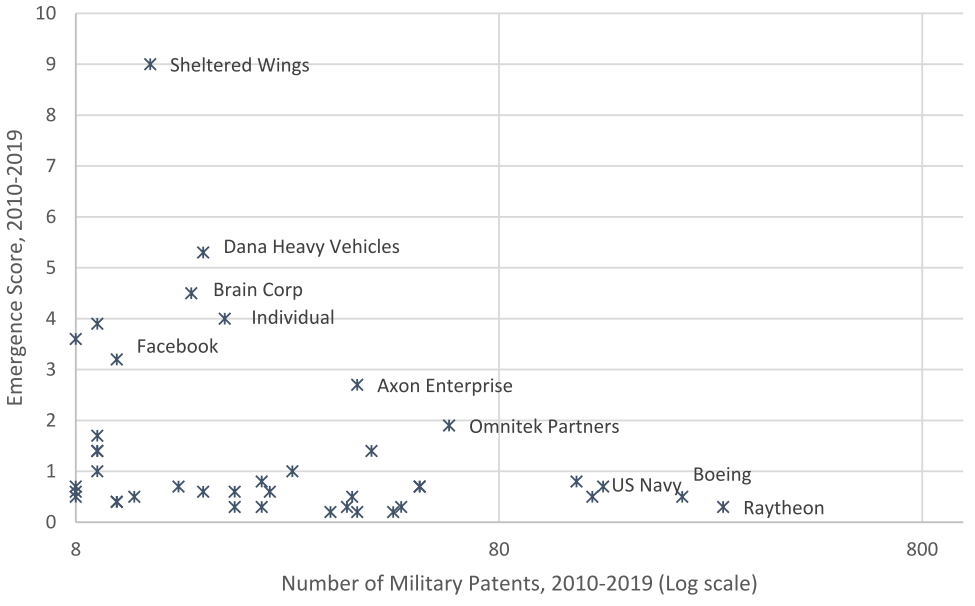

Figure 6. Emergence score vs. number of military patents by assignee, 2010-2019.

Implications the Defense Innovation Ecosystem

In the current international security environment – in which the United States is engaged in strategic competition with a technologically sophisticated power –, relative military technological advantage, and thus military technological innovation, is of particular importance for defense planners. Given, the dearth of empirical scholarship on the factors associated with a healthy defense innovation system, understanding the contributions of the organizations that comprise the defense innovation ecosystem is also of import to innovation scholars. So too is understanding the recent decrease in military technology emergence. By considering the distinct organizational contributions during periods of high and low emergence, insight into how to curate a healthy defense innovation ecosystem can be gleaned.

The most emergent period (1998-2007) during the last 40 years was characterized by substantial diversity in terms of the types of organizations that contributed to emergent military technology. This highly emergent period saw large contributions to emergence from non-traditional vendors, traditional defense contractors, large civilian-facing firms, and individuals. Further, the contributions of these distinct organizations varied by organization type. For example, individual assignees and non-traditional vendors tended to have average higher emergence scores but produced lower volumes of military patents. This suggests that in a healthy defense innovation ecosystem, individual assignees and non-traditional vendors may specialize in introducing novel ideas rather than producing new military technology patents *en masse*. That is, the system elements are not substitutable.

Additional evidence regarding specialization can be observed by comparing the plot of emergent organizations from 1980 to 1989 (Figure 4) to those from 1998 to 2007 (Figure 5) and 2010-2019 (Figure 6). The plots of the two more recent periods (Figures 5 and 6) reveals a conspicuous white space in the top right quadrant (high emergence + high military patent volume). During the 1980-1989 period (depicted in Figure 4) this space is occupied by large defense prime contractors (e.g. Hughes, Boeing) and the US Army labs. During the more recent periods, however, there are no organizations producing a high volume of military patents with high organization-level emergence scores. This may suggest increased recent specialization in terms the roles that are played by particular organization types within the defense innovation ecosystem. As described above, in

more recent periods, the data suggests that larger firms, especially defense primes, tend to produce the bulk of the military patents, while smaller non-traditional firms and individual inventors produce a high relative proportion highly emergent term. Such specialization is evident in Figures 5 and 6 were individuals and non-traditional vendors occupy the top left quadrant (high emergence + low military patent volume) while more traditional defense industrial base participants occupy the bottom right quadrant (low emergence + high military patent volume).

These observations suggests that policy attempting to ensure a healthy defense innovation ecosystem should seek organization-type diversity and should likely employ promotion strategies targeted at distinct organization types. For example, the finding that non-traditional vendors played a critical role in driving emergence during the highly emergent 1998-2007 period suggests that initiatives (e.g. the Small Business Innovation Research program or the creation of organizations such as Defense Innovation Unit, National Security Innovation Network, and DEFENSEWERX) directed at increasing non-traditional vendor participation are on sound empirical footing in their objective of advancing defense innovation. In contrast, there has been very little research or policy attention to the role of individual inventors in the defense innovation ecosystem. Given the critical role that individual inventors played in driving emergence during the 1998-2007 period and the reduced contribution of individual inventors during the low emergent 2010-2019 period, additional investigation into the contribution of individual to the defense innovation ecosystem is warranted.

Using USPTO patents results in a dataset that is overwhelmingly comprised of U.S. organizations. The results presented here are thus local to the U.S. defense innovation system. Conducting similar analysis on the patents generated by another country's defense innovation system may reveal insight into the character of their military technology innovation and their defense innovation base.

Implications for Revolutions in Military Affairs

Embedded in the idea of a revolution in military affairs is a claim that military technology change is revolutionary: characterized by periods of radical technological change. The evidence presented here gives provisional support for the RMA hypothesis. That is, there do appear to be enduring periods during which military technology innovation is particularly radical or revolutionary. The 1996 to 2008 period, which was characterized by a high overall military technology patent volume and a high number of emergent technical terms constitutes one of these periods.

What about particular RMAs? Raska (2021) claims that a new RMA has started, stating, that, 'since the mid-2010s, with the accelerating research and development of novel technologies such as artificial intelligence and autonomous systems, a new AI-driven RMA wave has already emerged' (Raska 2021, 2-3). Raska's AI-RMA is purported to be driven by three factors: the return to strategic competition and especially competition of military technology dominance between China and the United States, increased inter-disciplinarity in military-relevant scientific and technological fields such as synthetic biology and artificial intelligence (AI) or cyber and AI, and rapid diffusion of dual-use emerging technologies such as the integration of AI and the enablers of autonomy into modern weapon systems (Raska 2021, 14-15). The evidence presented here is not consistent with the proposition that we are currently in an RMA; recent periods exhibit low military technological emergence.

However, RMAs are conceptualized as the confluence of surges of technological, doctrinal, and organization innovation. As yet, little is known about the periodization and sequencing of these surges. How long do RMAs typically last? Does technological change typically precede (or even initiate?) doctrinal and organizational change? By identifying periods of high technological emergence and decoupling the technological component of the RMA construct, this article stakes a step towards answering these questions. Future researchers may consider where surges in new military doctrine, ideas, and organization fit within the technology chronology presented here. Perhaps the AI-RMA has begun, but not yet made its way into the military patenting corpus.

Implications for Theories of Military Innovation

This study was designed to detect and examine the temporal trend of military technology emergence, not to explain the causes of military technology emergence. However, the data reveal tantalizing evidence that in some cases threats may be driving military technology emergence. This finding is consistent with recent scholarship that has attempted to link a country's national security environment with its rate of innovative output (Taylor 2004, 2016; Schmid 2018b; Brummer 2020). The sections to follow consider the timing of two emergent terms – 'improvised explosive device' and 'terrorist' – to make the case that the onset of new threats likely drove rapid innovation in military technologies seeking to counter these threats. The findings constitute evidence that structural factors such as the external threat environment may drive military innovation.

The Term 'Improvised Explosive Device'

The emergence of the term 'improvised explosive device' is illustrative of the potential role of threats in driving military technology emergence. The term 'improvised explosive device' first appeared in a military patent in 1999. From 1999 to 2004, only eight patents containing the term 'improvised explosive device' were filed. In 2005, there were 17 patents filed containing the term. This dramatic jump in the occurrence of the term triggered – during the 1999-2005 analysis period – the first instance the term being classified as emergent. It was the second highest scoring term (based on emergence score) during this period, behind only 'explosive device.'[11] The term 'improvised explosive device' also met the emergence criteria during the 2000-2006 period; and was, in fact, the highest scoring term during this period. Over the next ten years, an additional 69 military patents containing the term were granted. Figure 7 displays the annual number of military patents containing the term 'improvised explosive device' from 1999 to 2019. What explains the dramatic surge in the occurrence of this term?

The dramatic surge in patents containing the term 'improvised explosive device' appears to be traced to the advent of a new threat and the resulting deluge of resources dedicated to countering that threat. In 2003, U.S. troops in Iraq and Afghanistan were increasingly being attacked by improvised explosive devices (IEDs).[12] In October 2003 Commander of the U.S. Central Command,

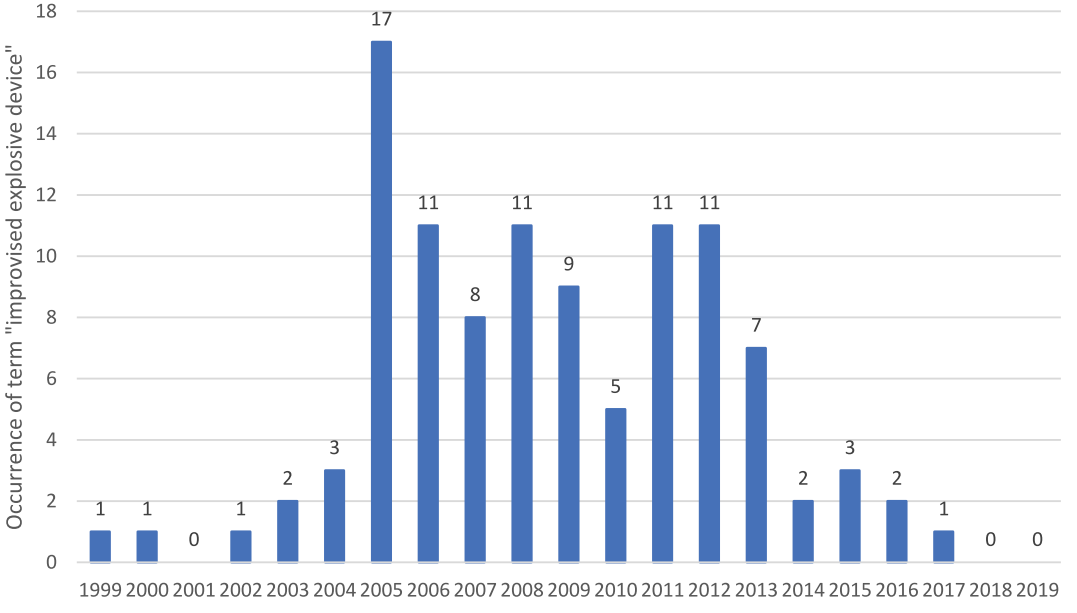

Figure 7. Military patents containing the term ' improvised explosive device', 1999-2019.

Gen. John Abizaid sent a memo to Secretary of Defense (Donald Rumsfeld) and the Chairman of the Joint Chiefs of Staff (Gen. Richard Myers) requesting an effort akin to the Manhattan Project to counter the threat. In response, during that same month the Army IED Task Force was stood up. In February 2006, this task force became the Joint Improvised Explosive Device Defeat Organization (JIEDDO), an organization that coordinated DoD efforts to counter IEDs with an annual budget of over US$ 3 Billion from FY2006 to FY2009. While JIEDDO's efficacy in countering the IED threat was mixed, the effort appears to have, at least, resulted in a surge in counter-IED patents.

Table 5 displays four 2005 patents containing the term 'improvised explosive device.' Each of the inventions focus explicitly on mitigating the IED threat through IED detection or IED disablement. Given the very low rates of counter IED patenting prior to 2005, these inventions – and the other military patents containing the term 'improvised explosive device' during the 2005 and 2006 surge – almost certainty represent inventions that were explicitly driven by the onset of the IED threat.

The Term 'Terrorist'

The time trend of the term 'terrorist' provides additional evidence of the role of threats in driving military innovation. Figure 8 shows the time series of military patents containing the term terrorist for the period 1995-2019. The figure shows that patents containing the term 'terrorist' were very infrequent until 2002. From 1995 (the first time the term appears in a military technology patent) until 2001 only three patents contained the term. Following the 11 September 2001, terrorist attack, patents containing the term were developed in earnest. This surge in patenting led to the term terrorist becoming emergent during two periods: 1995-2004 and 1996-2005.

As in the case of counter-IED patents, many of the patents in question explicitly address the threat in question. Table 6 displays four patents containing the term 'terrorist' that were filed in the year immediately following the 11 September 2001, terrorist attack. Each of the inventions focus on mitigating a terrorist threat.

As described in Section 2, the prevailing explanations for military innovation focus on domestic variables such as intra-service rivalry, inter-service competition, and civilian–military relations. The evidence provided here suggests that, at least in certain cases, the onset of external threats can initiate rapid military technology innovation. This finding is consistent with recent scholarship finding correlations between threats and military technology innovation (Schmid, Brummer, and Zachary Taylor 2017; Schmid 2018a). Importantly, however, the instances of threat-induced innovation presented here are insufficient to support a general case that military technology innovation is explained by external security threats. To do so would require consideration of the relationship between a larger set of threat conditions and instances or levels of military technology innovation.

With few exceptions (Acosta et al. 2018; Acosta et al. 2013; Schmid 2018), previous research into the character of the military technology innovation has taken a case study approach (see for example, Alic et al. 1992; Kulve and Smit 2003; Goldman and Eliason 2003; Bellais and Guichard 2006; Horowitz 2010). In fact, the lack of large sample investigation has been lamented by several

Table 5. Examples of military patents containing the term 'improvised explosive device'.

Year	Patent Title	Assignee
2005	Apparatus for real-time identification of selected components of e.g. trinitrotoluene of improvised explosive devices used by terrorists, has communication link provided between spectrometers to combine spectra into single spectrum	University of Wyoming
2005	Detection system used in military for detecting placement of explosive device within geographic area has sensors transmitting at least one of local and remote reporting signals to subset of sensors within the communication network	Textron Systems
2005	Expendable metal detector system for detecting improvised explosive device, has sensors sensing magnetic anomalies, and launcher launching detector for detecting metal to location suspected of containing metal	Johns Hopkins University
2005	Explosive device ignition system for disabling explosive devices from defensive perspective has vehicle that transports generator and electrodes, and which has boom that distally positions electrodes from generator	Applied Energetics

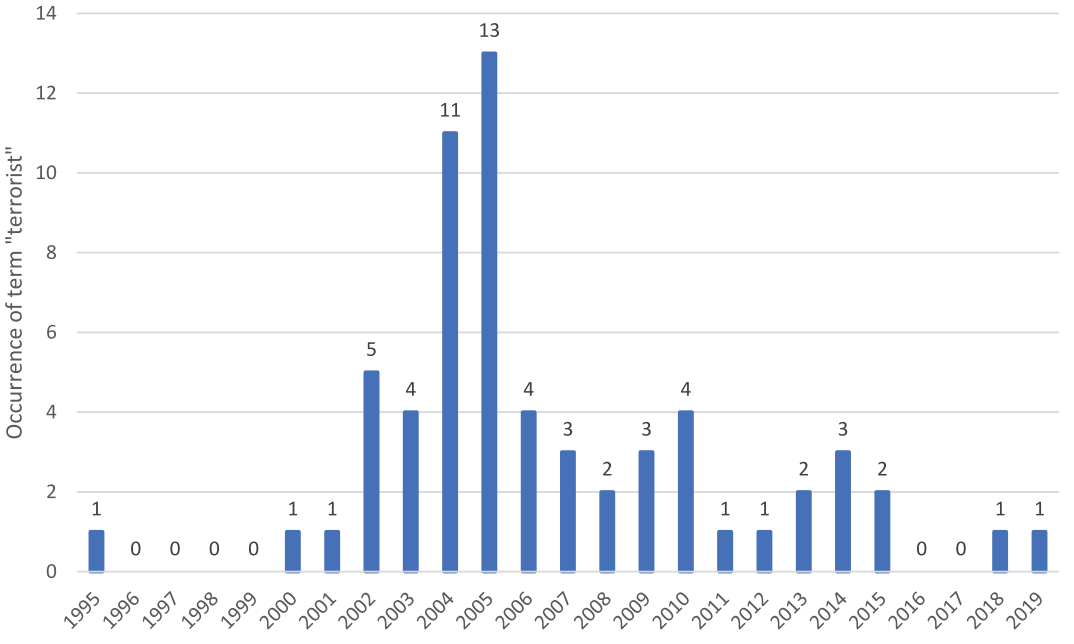

Figure 8. Military patents containing the term 'terrorist', 1995-2019.

Table 6. Examples of military patents containing the term 'terrorist'.

Year	Patent Title	Assignee
2002	Non-lethal gas device for use in commercial aircraft, has enclosed system with releasing unit which discharges volatile somnolent substance, containing nitrous oxide, chloroform, for inducing sleepiness to hijackers and passengers	Individual assignee
2002	Compact scanning apparatus to detect presence of e.g. plastic explosives, narcotics and chemicals while inspecting luggage and cargo, has infrared laser to illuminate interrogation surface area to selectively desorb e.g. explosive molecules	Control Screening LLC
2002	Cargo security method, involves applying X-rays with X-ray machine to freight and placing cover on freight by locking cover on freight with lock and activating alarm if hazardous materials within freight is detected	Freight Glove Technologies LLC
2002	Home-land intelligent system's technology for detecting deadly weapons of mass destruction and explosive devices, comprises transmitter, wireless communication unit, and sensor embedded in silicon substrate and etched inside a jacket	Individual assignee

scholars (see for example, MacKenzie 1989, 172 or Mowery 2012, 1712). The military patent data and emergence detection technique used here may avail researchers of novel, large-sample, methodological approaches. Such a research program may go far toward building a general explanation of the determinants of country-level or firm-level military technological innovation.

Notes

1. In the U.S., the Small Business Innovation Research program aims to increase participation in federal contracting by non-traditional vendors such as startups or other small businesses. There also exists defense-specific evidence of government efforts to increase participation by non-traditional vendors in government contracting. In the last decade, the Department of Defense's has created organizations such as Defense Innovation Unit, National Security Innovation Network, and DEFENSEWERX, all of which have increasing participation non-traditional defense contractors in their missions.

2. This finding suggests that the recent push within the United States Department of Defense to increase participation in defense contracting (e.g. through increased promotion of the Small Business Innovation Research program or the creation of organizations such as Defense Innovation Unit, National Security Innovation Network, and DEFENSEWERX) are on sound empirical ground.
3. Military technological superiority is by no means a sufficient condition for victory in war. The history of war provides many examples in which technologically superior forces fail to prevail. The case for the study of military technology that is made in this section, merely depends on the technology providing an advantage to its holder, even if not always a decisive one.
4. As there is sometimes a delay associated with populating the Derwent database, 2019 is the most recent year for which the data used here are mostly complete.
5. The use of patents filed at the USPTO facilitates the use of natural language processing because it assures that the patents in question were written in English. While the DII contains patent grant data from many other judications, the text fields in these data are often machine translated. Such machine translations often produce translations that use language that is inconsistent with that used by inventors in their native language and thus distort natural language processing techniques.
6. The term-extracting algorithm is also implemented using VantagePoint software.
7. Emergence score = 2* active period trend + recent period trend + mid-year to most recent year slope.
8. Porter et al. (2019) perform sensitivity analysis supporting the use of the 1.77 cutoff.
9. The patents granted to service- affiliated laboratories such as the Army Research Laboratory, the Air Force Research Laboratory, and the Office of Naval Research are typically granted to the military service branches. Thus, these patents appear in this analysis as associated with the service branch (e.g. US Navy). Litton Systems was a defense contractor eventually acquired by Northrop Grumman. Allied-Signal merged with Honeywell.
10. US Nary and US Army patents include those developed by Navy- and Army-affiliated laboratories.
11. There was substantial overlap in the patents containing the terms 'improvised explosive device' and 'explosive device.'
12. IED fatality data refers to the IED fatalities from Operation Enduring Freedom (OEF). OEF fatality data comes from http://icasualties.org/oef/

Disclosure Statement

No potential conflict of interest was reported by the author(s).

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