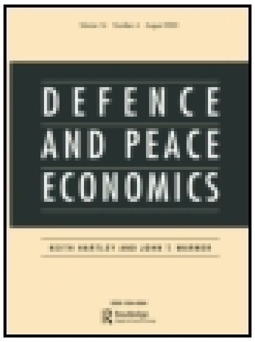

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Defence and Peace Economics

ISSN: 1024-2694 (Print) 1476-8267 (Online) Journal homepage: http://www.tandfonline.com/loi/gdpe20

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To cite this article: Jon Schmid (2017): The Diffusion of Military Technology, Defence and Peace Economics, DOI: 10.1080/10242694.2017.1292203

To link to this article: http://dx.doi.org/10.1080/10242694.2017.1292203

Published online: 17 Feb 2017.

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DEFENCE AND PEACE ECONOMICS, 2017
http://dx.doi.org/10.1080/10242694.2017.1292203

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The Diffusion of Military Technology

Jon Schmid

Sam Nunn School of International Affairs, Georgia Institute of Technology, Atlanta, GA, USA

ABSTRACT
The impact of national defense research and development spending on overall innovation depends on the extent to which the knowledge and technologies generated by defense funding diffuse. This article uses an original data-set 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.

ARTICLE HISTORY
Received 23 November 2016
Accepted 4 February 2017

KEYWORDS
Diffusion; innovation; military technology; patents; general-purpose technologies

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 article investigates the diffusion of defense-funded knowledge by considering the diffusion of the artifacts in which much of this knowledge is embedded: military technologies. Using an original data-set of patents filed by defense-servicing organizations, I use negative binomial and zero-inflated negative binomial (ZIBN) 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

CONTACT Jon Schmid jschmid11@gmail.com

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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.[1] There are several reasons for the persistence of this research gap. [2] 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). 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 Military R&D, Innovation, and Diffusion: A Review Section, 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 e.g. Alic et al. 1992; Goldman and Eliason 2003; Kulve and Smit 2003; Avadikyan, Cohendet, and Dupouët 2005; Bellais and Guichard 2006; Horowitz 2010).[3] 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 (2010, 1235, 1253) calls for the use of patent data to fill this empirical void. This article takes up this challenge and attempts to interrogate empirically, through the use of patent and patent citation data, some of the most common claims regarding the diffusion of military technologies.

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 and Mueller 1990; Mueller and Atesoglu 1993; Brumm 1997; Atesoglu 2002; Halicioğlu 2004).[4] Unfortunately, an equally broad variety of studies comes to the opposite conclusion (Faini, Annez, and Taylor 1984; Ward and Davis 1992; Mintz and Stevenson 1995; Mylonidis 2008; Dunne and Nikolaidou 2012; Shahbaz, Afza, and Shabbir 2013). 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 article proceeds as follows. Military R&D, Innovation, and Diffusion: A Review Section examines the existing scholarship on the diffusion of military technology and extracts four testable claims. Data and Methods Section outlines the data and methods used to test these hypotheses. Results Section presents the results. In A Potential Underlying Mechanism Section, I describe one potential explanation for the study's counterintuitive finding that military and civilian patents diffuse at similar rates. Conclusion Section concludes.

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

Military R&D and Innovation

Mowery (2010) proposes three channels by which defense expenditure can affect civilian innovation.[5] 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 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 eighteenth century (Ruttan 2006b; 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.[6] 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.

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 the extent to which these outputs diffuse within and outside of the system in which they originate.

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 (Peck and Scherer 1962; Alic et al. 1992; 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 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, Coronado, and Marín 2011; Acosta et al. 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.[7] 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).[8] 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 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.[9] 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).

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 (Alic et al. 1992; Winebrake 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, Coronado, and Marín (2011); Acosta et al. (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 IPRs 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, Guellec, and Martínez 2006; Woo, Jang, and Kim 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).

Table 1. 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	5408	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.

Data and Methods

To investigate the hypotheses enumerated above require information on the diffusion of military technologies, the diffusion of civilian technologies, patent characteristics, patent assignee characteristics, and IPR protection. Toward this end, I construct a data-set containing this information for 17,735 patent families over the period 2006–2010 (inclusive).[10] These patent families comprise inventions granted by over 40 national patent agencies. Table 1 summarizes the data employed in this study. Dependent Variable Section and Independent Variables Section define the construction of the variables used here and Model Section describes the model.

The majority of military technological innovation is concentrated within a small number of large diversified firms (Brooks 2005). 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). 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 are 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 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 article, 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, it is well documented that technological change drives change in doctrine (Murray and Millett 1998; Blasko 2011). The converse also holds up to empirical scrutiny. For example, Blasko finds that the United States' doctrinal

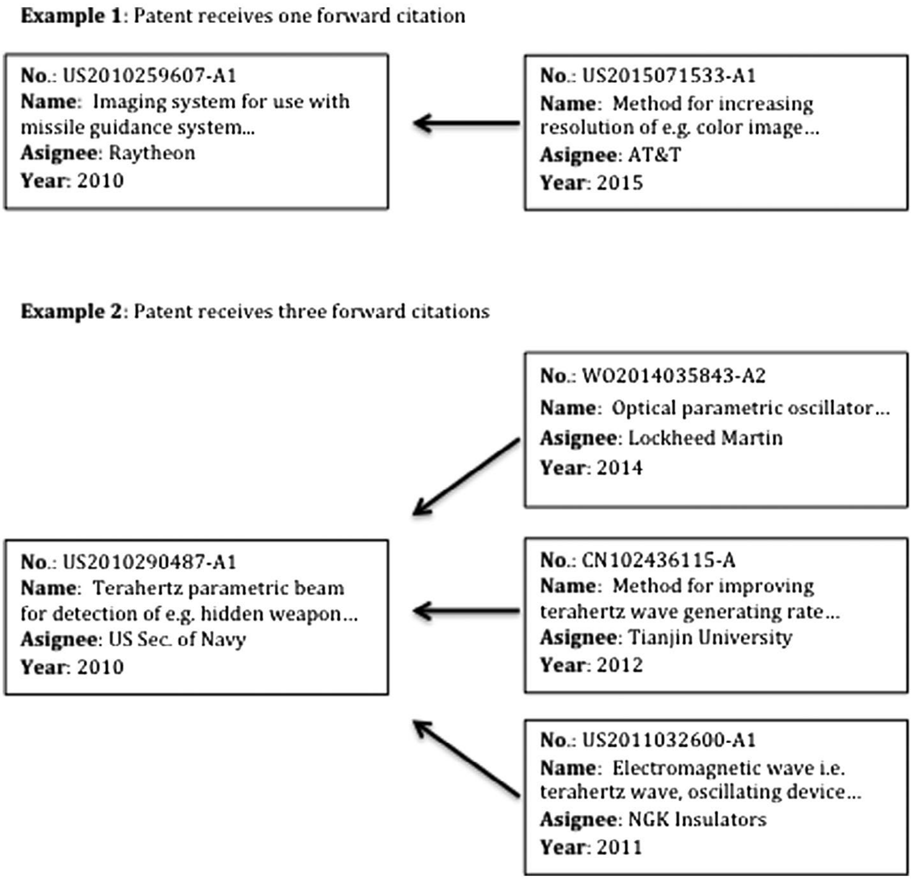

Figure 1. Diffusion as measured by forward patent citations.

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 illusive 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.[11] Forward 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 (Sorenson and Fleming 2004; Hoetker and Agarwal 2007; Verdolini and Galeotti 2011) and has been validated using firm-level survey data on technology use dispersion (Duguet and MacGarvie 2005). The forward citations counts 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 1 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.

Independent Variables

Military Technology

In testing H1, I distinguish military patents from civilian patents using the Derwent technology classification system.[12] 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 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 2112 military patents from 2006 to 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 2112 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, Coronado, and Marín (2011), Acosta et al. (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 4763 (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 dimension 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).

Table 2. 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*** (3.96)	0.0622* (2.37)	0.0597* (2.23)	0.0594* (2.03)
Tech. Domain	0.0141*** (15.86)	0.0239*** (5.46)	0.0237*** (5.16)	0.0190*** (4.18)
Jurisdictional Coverage	0.0703*** (14.52)	0.0482** (3.28)	0.0489*** (3.57)	0.0387* (2.54)
Year Dummies	YES	YES	YES	YES
Constant	0.610*** (13.25)	0.418** (2.90)	0.268 (1.92)	−4.594*** (−6.30)
Wald χ^2	1226.79	127.80	140.49	144.54
Alpha	1.89	1.83	1.80	1.78
Log pseudolikelihood	−33,448.85	−3987.16	−3979.70	−3104.83
Observations	17,735	2112	2112	1697

Notes: All coefficients are unstandardized. Robust *t*-statistics in parentheses.
*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

Table 3. 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*** (3.37)	0.0945* (2.53)	0.0919** (2.60)	0.194*** (4.05)
Tech. Domain	0.0159*** (7.78)	0.0231** (2.97)	0.0208** (2.70)	0.0399*** (4.20)
Jurisdictional Coverage	0.148*** (17.78)	0.137*** (5.47)	0.132*** (5.46)	0.128*** (4.12)
Year Dummies	YES	YES	YES	YES
Constant	−0.253** (−3.22)	−0.604** (−3.08)	−0.709*** (−4.34)	−0.436(−0.56)
Wald χ^2	1015.97	99.21	146.21	88.30
Alpha	1.83	1.57	1.52	1.54
Log pseudolikelihood	−12,444.20	−1655.68	−1650.22	−799.50
Observations	7698	1053	1053	638

Notes: All coefficients are unstandardized. Robust *t*-statistics in parentheses.
*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

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 et al. 2005). Because high quality innovations are more likely to diffuse 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.

Table 4. 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.

Model

Count data (i.e. data with values that are nonnegative and discrete) suggests the use of Poisson models (Hoffmann 2003). 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.[13] The positive value of the alpha parameters, reported in Tables 2 and 3, confirm that negative binomial regression is preferable to Poisson models in the present empirical setting. Robust standard errors are used to correct for heteroskedasticity.

Besides overdispersion, the data are also characterized by excess zeros; 7682 (43%) patents accumulated zero citations. Thus ZIBN are also estimated and presented in Appendix 2. 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.

Results

Table 2 presents the results of the negative binomial models predicting diffusion for the full sample. Table 3 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 percentage 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 4 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.

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.[14]

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 and 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 (not presented here in consideration of space) were run using only US patents, the technological experience variable turns negative and is significant at the 0.05 level.[15] 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 ZIBN specification (presented in Appendix 2), 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.[16] 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 the Diffusion of Military Technology Section, 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 toward 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 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.[17] Of the 70 patents that accumulated 30 or more forward citations, eight (0.038% of the total) were military while 62 (0.04%) 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.

A Potential Underlying Mechanism

Military R&D, Innovation, and Diffusion: A Review Section 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 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?* 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 have 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.[18] 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).

General-purpose technologies, by definition, will have large effects on subsequent innovation.[19] 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.

Conclusion

In this article 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.

Finally, it is important that the policy implications of the presented results not to 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.

Notes

1. The foundational NSI references are the volumes edited by Lundvall (1992) and Nelson (1993).
2. One notable exception to this pattern is Mowery (2009), which locates post-Cold War US defense spending within a NSI framework.
3. The only exceptions to which I am aware are studies by Acosta, Coronado, and Marín (2011); Acosta et al. (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.
4. For a summary of the debate concerning the relationship between defense spending and growth that focuses on the role of model selection see Dunne, Smith, and Willenbockel (2005). For a non-technical summary of the debate see Ram (1995). Alptekin and Levine (2012) preform a meta-analysis of 32 defense-growth relationship studies.
5. 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.
6. 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, Jaffe, and Trajtenberg (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.
7. 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.
8. 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.
9. 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.
10. 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.
11. 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.
12. In particular, patents are first filtered using Derwent Class Code 'W07' (Electrical Military Equipment and Weapons).
13. More precisely, I estimate what Cameron and Trivedi (2013) refer to as the mean-dispersion negative binomial model or 'NB2' in the authors' terminology.
14. 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 Guichard (2006) that the US does a better job than most countries in linking defense and non-defense sectors.
15. 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.

16. 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.
17. Removing the highly diffused patents leaves 17,665 observations for the test of H1, 2106 observations for the test of H2–H3, and 1692 observations for the test of H4.
18. 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 argues 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).
19. Bresnahan and Trajtenberg (1995) 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.

Acknowledgments

I thank James Bono, Jonathan Huang, Margaret Kosal, Seokbeom Kwon, Usha Nair-Reichert, Philip Shapira, Lindsey Sheppard, Wes Stayton, Adam Stulberg, Seokkyun Woo, and Frances Wren for their insightful comments on an earlier draft of this article. I also thank two anonymous referees for their careful and valuable feedback.

Disclosure statement

No potential conflict of interest was reported by the author.

ORCID

Jon Schmid http://orcid.org/0000-0002-2317-8966

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Appendix 1. 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 A1 provides these organizations and the fraction of their total patenting occupied by military technology patenting.

Table A1. 35 organizations used in analysis, share of total patenting occupied by military technology patents.

Organization	Military Weapons Patents (% of Total)
Alliant Techsystems Inc.	21.01
BAE Systems	14.89
Boeing Co	5.79
Bolotin N.B.	10.91
Deut Franzoesisches Forsch Inst	62.16
Diehl Bgt Defence Gmbh & Co kg	38.42
Eads Deut Gmbh	5.81
Exelis Inc.	30.93
Giat Ind SA	32.43
Harris Corp	7.34
Ihi Aerospace Co Ltd.	11.70
Inst Franco Allemand Rech Saint Louis	53.85
Instrument-Making Des Bur Unitary Enterp	34.79
ITT Mfg Enterprises Inc.	9.54
Krauss-Maffei Wegmann	20.83
Lfk Lenkflugkoerpersysteme Gmbh	49.38
Lockheed Martin Corp.	11.99
MBDA Uk Ltd.	57.45
Russian Military Academy	15.15
Nexter Systems	27.47
Northrop Grumman Corp.	6.94
Rafael Advanced Defense Systems Ltd.	23.53
Raytheon Co.	18.78
Rheinmetall Landsysteme Gmbh	19.53
Rheinmetall Waffe Munition Gmbh	27.12
Rockwell Collins Inc.	12.40
Saab Ab	23.05
Sagem Defense Securite	9.92
Sun L	6.54
Taser International Inc.	75.00
Thales SA	5.85
The Korean Agency of Defense Development	11.49
US Sec. of Air Force	9.52
US Sec. of Army	12.17
US Sec. of Navy	10.95

Source: Derwent Innovation Index.

Appendix 2. Zero-inflated negative binomial models

As a robustness check to the results presented in the paper's body, I also estimate ZINB models for diffusion. The results of the ZINB model for the full sample and the US-excluded sample are provided in Tables B1 and B2 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 (Greene 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 B1. 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	2112	2112	1697	17,735	2112	2112	1697
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***				

Note: All coefficients are unstandardized, *t*-statistics in parentheses.
$^*p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$.

Table B2. 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	7698	1053	1053	638	7698	1053	1053	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***				

Note: All coefficients are unstandardized, *t*-statistics in parentheses.
$^*p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$.