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Abstract

This study focuses on the spillover from the outcomes of military R&D to subsequent civil applications. We aim to identify the characteristics of those military innovations that are more likely to be exploited in civilian areas (i.e., dual use) and we build on previous literature to develop a methodology to identify such cases. Using both patent and citation data, we investigate country effects and invention-level characteristics that increase the likelihood to observe a military-to-civil knowledge spillover. We test these relationships by estimating probit, survival, and competing-event models on a large sample of military inventions filed between 2002 and 2012. Our results indicate that the incidence of dual use decreases during the period analysed and is heterogeneous across both technologies and countries. Military inventions having wider technological and geographical scopes are more likely to be cited by subsequent civil patents but military-to-civil spillovers occur later than military-to-military ones. Finally, the first dual use application of a military invention tends to appear within the country boundaries, suggesting that cross-border knowledge spillovers are not immediate. Our evidence is functional to the assessment of the potential indirect effects generated by the innovative activities of companies operating in the defence sector on the civilian sectors.

Keywords

Dual use, knowledge spillovers, patent, defence, innovation

1 Introduction

In most countries, public procurement to foster investments in defence and security is a relevant budgetary item. Spending on defence and security amounts to around 600 and 300 billion euros for the United States (US) and the European Union (EU), respectively (European Commission, 2017a). However, it is not only the size of the budget which is relevant, as there are also additional political and societal considerations. For example, the European Commission (2017a and 2017b) considers that defence and internal security are a way to foster cooperation and commonalities among EU member states.

Despite the size and political relevance of the industry, studies on the relationship between military investment – in particular, R&D – and economic growth provide mixed evidence (Ram, 1995; Morales-Ramos, 2002; Mowery, 2010). In part, this is due to the relationship between military and civilian R&D that shows complex dynamics in influencing the innovation activities. Defence investment can foster innovation through several channels such as the direct funding of civilian research bodies, civilian spin-offs from military entities, and public procurement (Mowery, 2010). Military R&D spending exerts a demand-pull effect that drives R&D investment for firms contracting with the government (García-Estévez and Trujillo-Baute, 2014). This might provide support to research organizations that develop also civilian innovations (Mowery, 2010; Ruttan, 2006). Indeed, an increase in the expenditure for defence and security can contribute to promoting the demand for new technologies through government procurement. Furthermore, defence technology suppliers can temporarily push the allocation of resources towards civilian projects (technology push-over) to overcome possible procurement downturns when approaching the end of large-scale projects (Klein, 2001). Finally, defence R&D activities can be beneficial to civilian innovation by simply increasing the overall knowledge and technological base (Mowery, 2010).

Anecdotal evidence supports the potential of military R&D spending in leading to the development of novel products with civilian applications (e.g., GPS, microwave oven). According to Ruttan (2006), military R&D has been a driving factor for the development of several high-tech industries in the US, noticeable examples are the computer industry and the development of the Internet from a military computer network. Nevertheless, the general consensus is that defence-related technologies have limited diffusion towards civilian applications, although previous research has not provided sufficient empirical evidence (Schmid, 2018). Our study aims to contribute to filling this gap by analysing the knowledge spillovers from military to civilian applications.

When addressing the relationship between military and civilian innovations, the term dual use is commonly applied with different nuances of meaning (Watkins, 1990; Molas-Gallart, 1997). Dual use technologies are innovations with applications in both the military and civilian sectors (Cowan and Foray, 1995). Dual use cases can be either captured by the direct transfer of specific technological components (Mowery and Rosenberg, 1991) or seen as a knowledge spillover: the defence research output provides a technological base to develop or improve products and processes throughout the whole economy (Cowan and Foray, 1995). Following this latter approach, we define dual use cases as the spillover stemming from military to civilian technologies and identify them by implementing a novel methodology based on patent citation data, which build on previous techniques (Acosta et al., 2011, 2018, 2020; Lee and Sohn, 2017).

The objective of our work is to improve the understanding of the characteristics of those inventions stemming from military to civil applications from a technological, temporal, and geographical point of view. Our empirical setting makes it possible to analyze several features of dual use innovations based on patent bibliometrics in terms of technological complexity and value. Technology-level specificities are investigated via sector dummies to highlight potential differences from traditional military fields (e.g., weapons and ammunition). These dimensions are explored with a set of probit models on a large sample of military inventions. Moreover, we contribute to the extant literature by analyzing the same attributes of dual use inventions in light of the dynamic features of the citation process using survival and competing-risks models to cope with data censorship and the elapsed time-to-citation. Finally, we investigate the geographical effects via the priority country (i.e., the most likely origin of the invention) and the incidence of dual use taking place outside the domestic borders, suggesting an international spillover of the national military investment, by resorting to a set of competing-risks models.

The results show that military technologies characterised by a broader technological scope, a larger team of inventors, or a wider geographical protection are more likely to provide a knowledge base for further civilian developments. Concerning sector specificities, the proportion of military innovations that have potentially been exploited in civilian domains is heterogeneous across technologies. In the largest military-related technological field by the number of patent filings (i.e., *other special machines*) that includes inventions on weapons and ammunition, the spillovers to civil applications are among the lowest, and those requiring more time to occur. Moreover, we find that the incidence of dual use is decreasing over the considered years. The results of previous analyses are confirmed by the survival and competing-risk ones. An increase in either the number of technical subclasses, the geographical scope, or the number of inventors, significantly prolongs the duration to observe a civil spillover with respect to a military one. Concerning the geographical localization of dual use, our findings indicate a marked heterogeneity among countries. More in detail, we empirically document that the knowledge spilling from defence-related patents with a first priority in the US has, on average, a higher probability to be used for civilian purposes confirming the previous results obtained by Acosta et al. (2011, 2020). Despite the increasing transnational dimension of technological development, countries still exhibit persistent differences with respect to the dual use phenomenon, suggesting that innovation and technology policies might be effective steering tools (Acs et al., 2017). Spillovers to civil applications are more likely to occur within the borders of a country and this is particularly pronounced in the US.

The rest of the paper is organised as follows. In section 2, we present the research framework and discuss previous literature on the matter. In section 3, we describe the dataset and the methodological framework. In section 4, we report both descriptive statistics and the main results of the econometric analysis. Finally, in section 5 we conclude.

2 Dual use technologies

The term dual use has been used in several circumstances to identify different concepts, such as the co-development of products, the civilian application of a military product, diffusion of military technology into civilian uses (or vice versa), and trade regulation of sensible products (Watkins, 1990; Molas-Gallart, 1997; Oltmann, 2015). Watkins (1990) suggested that in each specification – spin-off, transfer, diffusion, sharing of knowledge or products – the relevant aspect to consider is the capacity to assimilate technologies from other sectors. In other words, informational and spillover effects (Cowan and Foray, 1995) characterise dual use cases and can be considered the key dimensions when evaluating the contribution of military R&D investment to the overall economy.

Dual use innovations can be considered a special case of General-Purpose Technologies (GPTs) and Key Enabling Technologies (KETs). Bresnahan and Trajtenberg (1995) defined the concept of GPTs as those technologies characterized by pervasiveness, constant improvements, cumulative economic impact, that enable complementary innovations in other fields of application (Lipsey et al., 1998; Jovanovic and Rousseau, 2005; Teece, 2018; Scherrer, 2020). Examples of GPTs are printing, materials, the waterwheel, steam power, electricity, the internal combustion engine, lasers, and the Internet

(Lipsey et al., 1998; Rosenberg and Trajtenberg, 2004). Concerning the KETs, they can be considered a kind of GPT that has no clearly measurable economic impact, but that can generate direct or indirect economic and social benefits (Teece, 2018). For this reason, in the last decade some of the most relevant enabling technologies were included in the EU policies: micro and nanoelectronics, industrial biotechnology, advanced materials, nanotechnology, photonics, and advanced manufacturing (European Commission, 2017; Evangelista et al., 2018). With respect to the topic of this study, previous literature suggested that strategic military investments can spur the development of these types of technologies (Ruttan, 2006).

Evidence on the spillover effects of military R&D is rather mixed, providing inaccurate appraisals of their value and low informative power for R&D defence policies (Martí Sempere, 2018). On the one hand, the evolution of military technologies is strictly related to the nature of defence and security required by society. The traditional defence sector is transitioning to new technological areas where dual use applications are of high relevance (James and Teichler, 2014; Kepe et al., 2018). On the other hand, the spillover effects from military to civilian knowledge can be somehow limited. Defence programmes are often particularly complex, involving large R&D and non-R&D investments and many different actors[1]. The specificity of some pieces of knowledge produced within these projects may limit its reuse for further applications. In other words, the mission-oriented nature of defence R&D implies tailored developments that may limit the chance of fulfilling subsequent civilian needs. Moreover, the military focus on applied R&D means that funds for basic research are comparatively small (Martí Sempere, 2018), again limiting their contribution to the overall technological development (Mowery 2010). Finally, management and accounting principles favoured the creation of specialised departments within hybrid firms that keep their military and civilian divisions separate, as is the case of Boeing and EADS (Molas-Gallart, 1997). These barriers may lead to a weak interaction and integration of the military and civilian applications limiting the diffusion of military R&D knowledge and its knowledge externalities on the rest of the economy.

Spillovers depend on the way military programs are designed and integrated within the national systems of innovation (Nelson, 1993; Lundvall, 2007) and may depend on how programs are designed. For example, the development of the US computer software industry was influenced by the federal government policy after World War II. At that time, important shares of defence-related spending in software were allocated to the creation of a national infrastructure for the support of this new area of R&D, training, and technology development (Mowery and Langlois, 1996). Thus, the US orientation toward the development of generic technologies and basic science, targeting first-class universities, may have favoured the emergence of dual use applications.

In general, whenever governance mechanisms by national defence agencies foster a distributed innovative environment with connections to civil technological domains, further innovations as recombination from different technical areas can be developed, as suggested by Lazaric et al. (2011) and Avadikyan and Cohendet (2009) for the cases of France and UK in the 2000s. A radically different situation emerges when the national innovation system is strongly hierarchical and compartmentalised, and the government funding to military R&D is very concentrated around a small group of firms operating in the aerospace, nuclear, or arms industries, as in the case of France in the nineties (Chesnais, 1993; Serfati, 2000). In this context, intersectoral technological diffusion is less

[1] For example, the Eurofighter Typhoon program supported around 100,000 jobs directly and indirectly in hundreds of European companies (EC, 2013).

likely to occur (Serfati, 2000). Similar results have been found by Vekstein and Mehrez (1997) analysing Israeli policies: when civilian and defence technology policies are not coordinated with each other, they do not lead to a significant inter-organizational technology transfer and a socially effective defence conversion process is not achieved.

Spillovers and externalities may also relate to cultural aspects. In the Soviet tradition military and civilian research were separated and dual use cases were seen as *fortuitous side effects* (Bukkvoll et al., 2017, p. 245). The authors suggest that this is still the attitude within the Russian defence industry and limit the interaction between military and civilian actors in the development of new technologies.

Besides specific case studies, the empirical evidence on the relative size of the dual use phenomenon across countries is scant. Among the few empirical works dealing with the spillovers of military to civilian applications with a multi-country perspective is Acosta et al. (2013). The authors found, for a sample of around 600 military patents filed between 1998 and 2003, that those patents with the largest number of citations in subsequent civil patents are assigned to companies in UK, France, US, Japan, and Germany, in this order.

In our empirical application, we test whether some economies are systematically more likely to develop dual use innovations than others. In other words, we assess whether some countries generate an environment more conducive for knowledge to spill from military into civil innovations. From the previous findings of the literature, we expect that the US system, more integrated and with well-known examples of military R&D programs targeting basic research (Mowery and Langlois, 1996), produce a higher share of dual inventions than the rest of the world. Acosta et al. (2011, 2020) found evidence of higher incidence of dual use for the US and suggested that location is relevant in explaining both the spin-off (i.e., the transfers of technological knowledge from military to civilian domains) and the spin-in processes (i.e., those occurring withing the defence sectors).

Moreover, we also explore whether spillovers occur within the national borders and inter-country cross-fertilization differs across economic areas. Again, the specific structure of a national innovation system may lead to differences in the way knowledge spills within and outside a country. We deem these characteristics of spillovers particularly relevant when trying to evaluate the externalities of military R&D funding.

Dual use cases and the knowledge diffusion from military to civilian inventions may also depend on the type of innovations, this is an aspect of our investigation strictly connected to the empirical setting that we have developed. Indeed, the works trying to empirically investigate the dual use phenomenon are scarce and saddled with limitations (Schmid, 2018; Lee and Sohn, 2017). The presence of methodological problems when dealing with military R&D and technology transfer in terms of data availability and identification has been one of the major limiting factors. Patents and publications, the main sources of information about technologies, are not always disclosed when considering inventions of sensible nature or are disclosed only at the end of their life cycle. Thus, only a sub-sample of the total innovations produced by the defence sector is likely to be publicly available. However, this holds true for some civilian innovations as well; firms often rely on informal protection mechanisms for their innovations – e.g., trade secrets, lead time, or complexity – and the decision to patent is in part industry-specific (Hall et al., 2014). We do not have evidence to quantify to what extent the defence sector might differ from civil ones, and we will not tackle this issue in the present study.

As we said, the literature investigating the presence of military technological spillovers and their impact on the economy and innovation activities is mostly based on case studies (Alic et al., 1992; Chakrabarti et al., 1993; Chakrabarti and Dror, 1994; Smith, 1994; Maclin et al., 1994; Te Kulve and Smit, 2003; Avadikyan et al., 2005; Bellais and Guichard 2006; Kim et al., 2016). In this contribution, we aim at providing evidence on the technological spillovers using a large dataset of patent families, thus, overcoming the limitations of case studies. In fact, a wide range of technologies can be considered, and dual use cases can be characterised with quantitative measures following the literature on patentometrics (e.g., van Zeebroeck and van Pottelsberghe, 2011).

Few previous works investigated the characteristics of dual use cases with patent data and applied different methods to identify them. Acosta et al. (2018) found evidence that it is more likely to observe the diffusion of knowledge from military to civilian patents when the seed defence patent has a dual nature, i.e., it is associated with both military-specific technological codes and non-military ones[2]. Lee and Sohn (2017) focused on the quality of the innovations (proxied by patent renewals) and found a positive relationship between the value of military technology and duality, measured as the ratio of forward citations by the civilian sector over the total number of citations. From a dataset of military patents belonging to Norwegian defence firms, Enger (2013) found that knowledge diffusion from military to other fields is positively related to collaboration with research organizations and the technological scope of the patent.

In this work, we will consider three patent-level measures to characterise military innovations and dual use cases: the technological scope of a military invention, the size of the team of inventors, and its geographical scope. A broader technological scope is likely to be inversely related to the specificity of the piece of new knowledge and to find different applications (OECD, 2009). Therefore, we expect that the broader the technological scope of a military invention, the higher the probability of being re-used in the civil domain. The number of inventors provides an indication of both the complexity of the invention and the collaborative effort required to develop the invention (van Zeebroeck and van Pottelsberghe, 2011). Finally, the geographical scope of an invention, that is the number of countries in which protection has been sought, can be a signal of its prospective commercial value (e.g., Harhoff et al., 2003; van Zeebroeck and van Pottelsberghe, 2011). Military patents having a wider geographical scope might be closer to commercial applications and more easily accessed by inventors from different jurisdictions.

3 Method and data collection

The identification of dual use cases starts with the identification of military innovations. Our method is based on the analysis of patent data collected from PATSTAT, the European Patent Office (EPO) Worldwide Patent Statistical Database[3]. The analysis is based on patents filed between 2002 and 2012, which grants sufficient time to collect information on patent citations. We consider patents filed at the largest patent offices: the European Patent Office (EPO), the United States Patent and Trademark Office (USPTO), the Japan Patent Office (JPO), the Korean Intellectual Property Office

[2] Section 3 will describe the previous methods of identification with respect to the proposed one.

[3] We use the *Autumn Edition*, 2017. PATSTAT contains bibliographical and legal information relating to more than 100 million patent documents that have been filed in 90 different patent issuing authorities.

(KIPO), all the member states of the European Patent Convention (EPC)[4], Canada, India, Israel, and Russia. Although the number of patent filings at the Chinese Patent Office is booming, we excluded it from the analysis because it would have introduced a significant noise in the data, deriving from the complex process to identify and select military Chinese companies as well as their corporate trees.

We recognise that patents represent only an imperfect and partial indicator of the results stemming from R&D activities. Such limitation might be further amplified for defence patents due to the presence of inventions that could be patentable but are kept secret because of the sensitive nature of their technological content. Despite these shortcomings, patent data provide a rich set of observations allowing for large-scale and comprehensive analyses compared to alternative approaches based on case studies (see, for instance, Hartley, 2006).

3.1 Identification of defence innovations

We propose a methodology to identify defence innovations that builds on methods proposed in the literature, extending them with a combination of multiple criteria. The few studies that employed a quantitative identification strategy relied mainly on the International Patent Classification (IPC) codes reported in the patent documents. The most specific are the IPC classes F41 and F42 concerning *Weapons*, and *Ammunition and blasting* (Acosta et al., 2011; Lee and Sohn, 2017); additional IPC codes were introduced by Acosta et al. (2018). The use of military-specific IPC codes significantly limits the inclusion of false-positive results: patents associated with weapons and ammunition are frequently actual military-specific innovations. However, the trade-off from imposing such a strict criterion is that it does not allow to cover many technology fields where defence companies are active, e.g., air and naval vessels, special fabrics, communication and networking devices. Such limitation affects both companies with a dual nature, such as *Boeing* or *Airbus* that develop civil and military airplanes, and companies with military-driven activities, such as *L3 Technologies* or *Harris Corporation*. The limitation has already been pointed out by previous studies (Lee and Sohn, 2017; Schmid, 2018).

A recent work (Burmaoglu and Saritas, 2017) applied a keyword search to identify military patents. However, even if disclosed by a military-specific firm, inventions and scientific advancements often do not directly mention their application for warfare purposes[5]. Furthermore, some of the largest corporations investing in defence and security R&D have both civil and military lines of business (e.g., *Airbus*, *Honeywell*, *General Electric*).

Therefore, we develop a method based on the application of three different criteria of inclusion to identify a defence patent: i) the patent is associated with a military IPC code; ii) the patent belongs to a military firm; iii) defence-specific keywords are reported in the patent text fields. Table A.3 in the Appendix reports the complete list of the IPC codes that have been derived from previous studies

[4] To date, the EPC has 38 contracting states: Albania, Austria, Belgium, Bulgaria, Switzerland, Cyprus, Czech Republic, Germany, Denmark, Estonia, Spain, Finland, France, United Kingdom, Greece, Croatia, Hungary, Ireland, Iceland, Italy, Liechtenstein, Lithuania, Luxembourg, Latvia, Monaco, Macedonia, Malta, Netherlands, Norway, Poland, Portugal, Romania, Serbia, Sweden, Slovenia, Slovakia, San Marino, and Turkey.

[5] By way of example, the description of an airplane engine is the same for both civil and military aircrafts and its final application might not even be specified on patent documents.

(Acosta et al., 2011, 2018)[6] as well as the semantic analysis looking at the presence of defence-related keywords within the textual descriptions of the IPC system[7].

Concerning the second criterion, patents are included in the sample if they have been filed by a company or a governmental agency with core activities in the military sector. We start from the works of Acosta et al. (2018, 2020) and Schmid (2018) who introduced in their patent identification strategy a set of defence firms with the aim to improve the perimeter of the analysis. We recover defence companies from the *Stockholm International Peace Research Institute* (SIPRI) database[8] and the *Register of the Certified Defence-related Enterprises* (CERTIDER)[9] of the European Commission. The SIPRI database provides comprehensive information on more than 200 international public and private military manufacturing and services firms. From these datasets, we consider the organizations with at least half of their revenues coming from weapon sales and add their patents to the final sample of defence innovations. We introduce this additional selection criterion on firms to cope with the previously mentioned caveat on companies having a dual nature. Relying on public online information on the business activities of the selected firms, we performed an extensive manual check of the companies, and we were able to separate defence subsidiaries or business units for companies such as *Diehl*, *Meggit*, and *Snecma* that have both military and civil activities. The goal of this process was to reduce the occurrence of false-positive results due to two possible reasons. First, large corporations active in several businesses and technological fields (e.g., *General Electric*) may have only a small fraction of patents in their portfolio related to military activities[10]. Second, several categories of vehicles (e.g., aircrafts, helicopters, ships) have a dual use by nature, since they can be used both in warfare and in civil applications (e.g., transportation of goods and people, rescue, medical assistance). After excluding firms having either a portfolio of mixed activities or no patent applications filed in the considered time period, the process led to the identification of 178 firms that develop innovations for the defence sector. The sample of patent assignees is enriched with the inclusion of national armed forces or defence agencies (e.g., *US Navy*, *US Air Force*). Firm and agency names have been searched in the assignee field applying queries that account for potential name changes, spelling errors, or acronyms. As further robustness checks, we screened the list of retrieved assignees to avoid the inclusion of companies with similar names that are not active in defence-related markets and subsequently reviewed the most frequent IPC codes associated with their patents to verify the attribution in terms of industry coverage.

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[6] We also include all the IPC sub-classes linked with the ISIC codes of defence-related activities (i.e., 2520 and 3040) in the probabilistic crosswalk of Lybbert and Zolas (2014).

[7] We further tested for the presence of false positives in the results. In particular, several exclusion conditions based on specific keywords, firm names, and IPC codes have been employed. Patents covering *games*, *toys*, or *sport* and identified by means of keywords or via the IPC code *A63* (*Sports; games; amusements*) were not included. Patents on airbag systems found using keywords (*airbag*, *seatbelt*, *pretensioner*) or the presence of the IPC code *F42* in combination with one between *B60R 21* (*Arrangements or fittings on vehicles for protecting or preventing injuries to occupants or pedestrians in case of accidents or other traffic risks*) or *B60R 22* (*Safety belts or body harnesses in vehicles*) have been excluded from the sample. Patents filed by companies having in their names the terms *airbag* or *toy* were not included.

[8] Publicly available at https://sipri.org/databases (last accessed in January 2018).

[9] Publicly available at https://ec.europa.eu/growth/tools-databases/certider (last accessed in January 2018).

[10] Despite these hybrid companies are not included *per se* (e.g., Boeing and Airbus), their military-specific inventions are very likely to be added to the final sample thanks to the other selection criteria.

The final criterion of inclusion in the defence sample relies on the search of keywords linked to the defence sector in the main text fields (i.e., title, abstract, and claims) of patent documents[11].

The final dataset includes 177,143 military patent applications corresponding to 63,615 patent families[12]. Patent families are considered an accurate measure of the inventive activity that is not affected by duplicates of patent documents extended to multiple national offices and jurisdictions (OECD, 2009; Trippe, 2015). Also, the use of patent families helps to draw a better representation of the patent citation network that serves to identify dual use innovations.

The proposed identification strategy aims to be inclusive since military firms innovate also outside the fields of weapons and ammunition, which are the technological areas traditionally associated with military activities. At the same time, there are defence inventions that are developed by firms (or individuals) that are not listed in the available repositories of military companies (or government agencies). The selection criteria overlap marginally. About 25% of the patent families in the sample satisfy more than one criterion of inclusion (the largest overlap is between IPC codes and keywords, 14%). The three selection conditions – firm, IPC codes, and keywords – contributed uniquely for 43%, 27%, and 5% respectively. These findings support the choice to introduce multiple entry criteria to define the defence perimeter.

3.2 Operationalisation of the definition of dual use

Once defence innovations are identified, the empirical strategy requires a method to assess the dual use concept. Previous empirical works operationalised dual use through co-classification of IPC codes. Starting from such data structure, scholars studied the diffusion of military technologies exploiting the patent citation network. Schmid (2018) applied the count of forward citations as a measure of diffusion with no distinction on the nature of the citing patents (military or civilian) since the aim was to compare the diffusion levels of the two types of innovations. Acosta et al. (2018) and Lee and Sohn (2017) identified the nature of citing patents, i.e., military or civilian (relying only on IPC codes) to study knowledge diffusion with reference to the dual use of the innovations.

We extend the approach of the latter works and operationalise the definition of dual use by relying on citation flows. Starting from the seminal papers by Griliches (1979, 1990) and Clark (1976), patent citation data have been extensively used by many scholars to empirically assess several characteristics of the underlying inventions or to measure the occurrence of knowledge spillovers between inventors, organizations, geographical regions, and technical domains (Jaffe et al., 2019). Aggregate patent citations can be regarded as a valid, although noisy, indicator of the occurrence of knowledge transfers between individuals (Jaffe, 2000)[13]. However, several issues should be considered when using patent

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[11] Most of the searched terms are English words, however, a multilingual approach was employed for some of them (e.g., *military*). The text searches tried to avoid false-positive results by manually checking the retrieved records (e.g., *tank*, *warhead* returns several non-military patents). The employed method is the same described in the work of Caviggioli et al. (2018).

[12] A set of patents that are related to each other, either directly or indirectly, by means of priority claims and cover the same technical content. We reconstruct patent families via INPADOC identifiers. Please note that a random selection of 200 patents identified as military was manually checked to validate the presence of potential false positives: no patent was found as misclassified in light of our understanding of the field of application of the protected invention.

[13] The author surveyed two groups of inventors associated with patents granted between 1985 and 1993 to test whether the presence of backward and forward citations on the focal documents implied or not actual flows

citation data. These are related to a series of factors, such as differences in administrative procedures across patent offices, idiosyncratic characteristics of technology fields, the presence of time effects, the heterogeneous practices of patent examiners, and the strategic incentives of applicants to disclose known and relevant prior art (Jaffe and De Rassenfosse, 2019).

Dual use patent families are defence inventions that are cited by subsequent non-military technologies. The use of citations does not allow to identify those inventions that are dual *per se* but only when there is a subsequent application in a civil field. However, the approach overcomes the problem of considering as dual the inventions that combine military and civil IPC codes (Acosta et al., 2011, 2018; Lee and Sohn, 2017) but possibly having only a military application (e.g., a laser target for a gun is associated to optics and weapons IPC codes, but its usage is purely military). In particular, we consider a patent family to be dual when at least one of its forward citations does not belong to the sample of defence inventions and has not been filed by one of the firms listed in the SIPRI or the CERTIDER database[14].

4 Data

In our sample, 38,733 families (61%) have been cited by at least one subsequent patent. The inventions were cited by subsequent patents classified either as military (32%), or civil (27%), or both military and civil (41%). The aggregate evidence is that 42% of the examined military patent families have been cited by a civil patent and thus fall in the proposed definition of dual use inventions.

The distribution of military innovations that have a subsequent civil application is not homogenous across technological sectors. Interestingly, the largest technical field (43% of the whole sample of military patents) in the database – *Other special machines including weapons and ammunition* – shows the lowest share of dual use cases (26.3%), a value similar to the result reported by Acosta et al. (2013). Among the technological fields with an above-average proportion of dual use inventions are *Medical technology* and those related to *Electrical engineering* with 56.6% and 64.1% of dual use cases, respectively. Table A.2 in the Appendix provides details of military inventions, the incidence of dual use cases for all technological fields[15], and the growth of dual use cases computed between 2002-05 and 2006-09. Note that the technological fields with the highest increase in terms of dual innovations are *Computer technology* (30.2%), *Control* (18.4%), *Digital communication* (15.3%), and *Audio-visual technology* (14.9%). Conversely, the technological domains having a substantial decrease over time in the number of dual use cases are *Other special machines including weapons and ammunition* (-20.6%), Optics (-17.3%), and Telecommunications (-14.1%). The combined evidence on growth rates seems to indicate that in recent years (i.e., from 2006 to 2009) military innovations with subsequent applications in civilian domains have appeared with a lower incidence in areas belonging to the macro-

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of knowledge. He finds that about half of the connections indicated by patent citations correspond to spillovers between inventors. They are perceived to be stronger whenever the cited patent is more recent, associated with a geographically closer location and larger technical merit.

[14] Hence, receiving a citation from a patent assigned to a firm generating only a small proportion of its turnover from armaments sales (i.e., lower than the inclusion threshold) is not a sufficient condition for the focal innovation to be dual.

[15] Please note that a few sectors reported in the table have limited military applicability (e.g., pharmaceuticals, food chemistry, furniture, games, other consumer goods, civil engineering).

sectors of *Mechanical engineering* and *Chemistry* and more frequently in the fields related to *Electrical engineering*.

Table 1 reports the incidence of dual use cases across patent offices (POs), a proxy for the source country of defence innovations (De Marco et al., 2017). The PO with the largest number of dual use inventions is the USPTO, which represents about 29% of the total dual use cases identified in the sample of military inventions. The United States is also the priority country where the share of dual use inventions on total military patents is the highest (64.7%). The PO with the lowest share (5.0%) is the patent office of the Russian Federation (Rospatent). The comparison across countries of origin shows that the phenomenon of dual use is heterogeneous.

[Table 1 here]

With the aim of providing insights on the innovators in defence-related technologies, we improved the identification of assignees by cleaning and consolidating their names more accurately than the original standardised values available in PATSTAT. To this end, we exploited a combination of automated clustering algorithms[16] as well as manual checks. The process improved the identification of assignees and reduced the number of different entities by about 5%.

The twenty largest assignees of defence innovations, which patent portfolio represents 39.8% of the whole sample, are reported in Table 2. The list includes firms, conglomerates, and governmental bodies. The organizations with more than 1,000 inventions (mostly US-based) represent instead a cumulative share equal to 30.4%. The number of different patent assignees increased more than threefold between 2002 (2,421 entities) and 2011 (8,059 entities), with a slight decrease in the last year observed. However, the concentration of the innovative activities in terms of patent families owned by the 20 largest innovators is quite constant in the time frame, about 40%. This suggests that the contribution to the overall sample of defence innovations of new entrant organizations is relatively marginal.

[Table 2 here]

Finally, to provide insights on the most recent developments of dual technologies, we focused on the dual use patent families developed in the years from 2010 to 2012. According to the automated reporting analyses provided by *Clarivate Analytics*[17], the defence inventions of this area were related in particular to the following technologies: i) unmanned aerial vehicles and drones; ii) human-machine interfaces such as touch screens, virtual and augmented reality, iii) data storage and security (e.g., blockchain, cloud) and transmitting (e.g., beamforking)[18].

[16] We used *OpenRefine*, an open-source tool available online at https://openrefine.org.

[17] We uploaded the list of identified military patents into the *Derwent Innovation* web platform (https://clarivate.com/derwent/solutions/derwent-innovation/, last accessed in March 2021) that provides an automated cluster analysis based on IPC codes and frequently mentioned concepts. We reported a summary of the results.

[18] Note that such inventions were not necessarily the first of their kind, but they might rely on previous civil patents and then lead to other civilian developments. Some specific examples are the following: *Amazon's* patent US10000284B1 is about a drone and cites previous inventions of *Lockheed* and *Northrop Grumman*; *Tesla's* patent US20120160088A1 is about a *Vehicle battery pack ballistic shield* and is based on inventions on armoured vehicles; *Microsoft's* patent US9508195B2 is about glasses for providing interactive augmented reality environment and cite *Lockheed's* ones.

5 Empirical analysis

The empirical analyses carried out in this study explore different aspects of the identified dual use inventions. The first set of tests compares the geographical origins and the patent-level characteristics of dual use cases with the rest of the military patents. Since the operationalization of the definition of dual use is based on the presence of citations, we perform a second set of analyses using survival models on the sample of military patents to deal with the hazard and the elapsed time to receive a citation. In the third set of analyses, the geographical dimension is further characterised to distinguish between domestic and international knowledge spillover and examined in survival models with competing effects.

Table 3 reports a number of descriptive statistics for the investigated variables. The variable *dual use* is a dummy equal to 1 whenever the focal patent family has a civilian forward citation and 0 otherwise. It will be employed as the dependent variable in the first set of probit models.

Several time measures are computed. The origin date of each invention is the earliest priority date of the patent family. The number of days elapsed to the first citation received is on average 1,145 (more than 38 months)[19]. The time to the first civil citation is on average 15 days longer than to the first military one (1,309 and 1,294 days respectively). Among the first civil citations, those originated from a new invention in the same country take on average 177 days (almost 6 months) less than those from a foreign invention. These values are further discussed in the next sections that introduce the survival and competing events models.

We collected additional information at the patent family level: the number of IPC sub-classes (*technological scope*), the number of inventors (*inventors*), and the number of application countries where patent protection has been sought (*geographical scope*). Dummy variables for the first priority office (i.e., USPTO, EPC, JPO, KIPO, Rospatent, or the rest of the world) have been included in all the specifications.

[Table 3 here]

Table A.1 in the Appendix provides the mean and the standard error of all variables employed in the econometric models for different sub-samples of military patent families identified through the entry criteria as well as for the intersection of the three. The relative share of dual patent families is higher (and the time-to-dual is shorter) for the set of innovations selected through the list of military firms. Such evidence may be due to the presence of inventions filed by companies that perform their core activities in defence-related sectors but are part of larger groups that have additional business units operating in civil markets. Interestingly, patent families belonging to the set identified jointly by the three selection criteria have on average a larger number of IPC sub-classes (i.e., at four digits) indicating a broader technological scope and thus a higher potential redeployability of the underlying

[19] There are cases where the priority date of the citing family is earlier than the priority date of the cited one. They represent 11% of military citations and 8% of civil citations. These negative time differences seem due to the presence of an outlier patent, older than the rest of the members of the citing family. We hypothesise that this situation occurs during very long patenting procedures, when a recent invention is added as backward citation even if it is younger than the patent document under examination. However, we cannot rule out the presence of errors in the reconstruction of the INPADOC patent families. These cases are excluded from the survival analyses.

innovations as well as a larger geographical coverage of the legal protection (i.e., family size) in terms of publication countries.

5.1 Likelihood of dual use inventions

The first set of estimations compare dual versus non-dual military patents. Table 4 shows a set of probit models where the dependent variable distinguishes dual use cases, controlling for technological fields (identified through the IPC-WIPO concordance table[20]) and time intervals.

[Table 4 here]

Concerning the geographical origin of dual use inventions, the omitted dummy is the rest of the world. Patent families that have a first priority at the USPTO are more frequently associated with dual use than any other group[21], the related average marginal effect is 24.5%. The Russian patent office is the one with the lowest incidence of dual use cases, corresponding to a decrease in the probability of 24.0%, and this difference is statistically significant. The results seem to confirm the presence of heterogeneity across origin countries. In terms of bibliometric characteristics, dual use patents are positively and significantly associated with wider technological and geographical scopes and filed by more complex research groups. In particular, the probability of dual use increases on average by 3.1%, 0.7%, and 1.7% for each additional patent sub-class, inventor, and publication country respectively. Military patented inventions that are more easily re-deployable in other technological domains, developed by a larger team of inventors, and with a broader geographical protection are more likely to find subsequent civil applications[22]. Time dummies, either used as intervals (see Table 4, where the omitted category is the first interval) or as year indicator variables (Table A.4 in the Appendix), show a decreasing trend but this result could be influenced by the citation lag given that patents that were not dual when we collected the data, could become so in the future. The survival models described in the next sections will provide further evidence by controlling for this type of truncation.

Table A.5 in the Appendix provides robustness tests that try to disentangle the effect of the largest military field in the sample, Other special machines (43%), which includes the IPC codes of inventions related to weapons and ammunition. The contribution of this field is particularly negative to the generation of civil spillovers. Further robustness checks have been performed with the variables in logarithms[23].

The main econometric results are also robust to the use of different sub-samples of military patent families that have been selected with respect to the number of citations received (Table A.6 in the

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[20] The WIPO-IPC concordance schema maps IPC codes into 35 technological fields and is publicly available online at https://wipo.int/export/sites/www/ipstats/en/statistics/patents/xls/ipc_technology.xls (last accessed in January 2018).

[21] This result is confirmed when the same probit models are tested by excluding each country at a time. They are not reported but are made available on request.

[22] In the Appendix, we report several econometric analyses on the robustness of the results to alternative specifications of the empirical models. In particular, we test whether our findings are affected by i) the inclusion of year indicator variables in the regressions as controls instead of interval dummies to capture the presence of aggregate trends, ii) considering sub-samples of patent families that are external or internal to the field *Other special machines including weapons and ammunition* or adding a specific technological sector dummy, iii) the use of regressors on patentometrics transformed in logarithms, and iv) employing different sub-samples of military innovations with respect to the overall number of citations received. Our baseline results are stable across such robustness checks.

[23] The results, available on request, are consistent with those shown in the paper.

Appendix). We estimated regressions with sets of military innovations having exactly one or at least one forward citation, and values above the median or the mean of the sample distribution of forward patent references. Moreover, we also tested our models with partitions of the main sample of defence inventions that satisfy one, two, or all the three identification criteria, respectively. These results are available on request.

5.2 Time to civil and military citations

The second part of our analyses considers the dynamic features of the citation process using econometric models that cope with data censorship and the elapsed time to citation. The citing mechanism implies that recent patents have a lower likelihood to receive a citation, because of the shorter exposure to the risk of being cited, and therefore a lower hazard to be considered dual in our empirical framework.

First, we focus on the subsample of cited inventions to compare patents having at least one military forward citation with those having at least a civil one. As shown in Table 3, the number of days for a military patent to receive a civil citation is on average 15 days longer than the time to receive a first military citation. Although the time difference between the occurrence of a military and a civil spillover is not large in absolute terms, it varies greatly across the technological sectors. The field *Other special machines* reports the largest mean difference with the military spillover occurring 402 days earlier than the civil one. On the opposite side, in *Biotechnology*, a field requiring very high R&D investment per invention (Gkotsis and Vezzani, 2020), the first civil citation appears on average 531 days earlier than a military one.

Concerning the general trend of the dual use phenomenon, Figure 1 shows the relatively faster decrease for families with at least one civil citation with respect to those with military ones. This points in the direction of a potential fall-off in military to non-military technology spillover. The evidence also suggests that knowledge flows occurring inside the perimeter of military technologies are faster than those crossing the boundary from military to civil domain. The result appears even more robust when considering that the civilian pool of potential citing documents is much larger than the military pool.

[Figure 1 here]

Table 5 displays the results of maximum likelihood estimations for parametric regression survival-time where the *failure* event is the occurrence of the first civil citation, that is the first dual use. We report the median survival times predicted by the log-logistic model[24]. Such a probability distribution is employed for events whose rate is assumed to increase initially and decrease later (Bennett, 1983). Negative amounts represent a shorter time to the occurrence of the first civil citation, i.e., a higher likelihood of observing a dual use case. Findings are coherent with the previous probit models. all else equal, military patent families with a first priority at the UPSTO are faster in receiving a civil application than any other country, whereas the slowest patent office of origin is the Russian one. Patent families with broader technical and geographical scopes, as well as those involving larger teams of inventors, are associated with a shorter time to receive their first civil citation, that is a higher likelihood of being dual. Concerning the trend, the results show that in recent years the average time for a military patent to become dual has increased.

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[24] The log-logistic survival model was selected among the available distributions according to the Akaike Information Criterion (AIC).

Table A.7 in the Appendix focuses on the impact of the largest military technological field, *Other special machines*. The results are robust with those reported in the models of Table 5 and are coherent with those of the probit specifications (Table A.5 in the Appendix). In particular, the field requires a significantly higher amount of time to generate dual inventions, but this does however not influence the findings of the general models.

[Table 5 here]

The next set of econometric models aims to directly compare civil or military spillovers, therefore considering the different times to receive a military or civil citation. The competing-risks models have been implemented with a specific procedure[25] to cope with the long computational time due to the large size of the study sample. Data for estimating and modelling cause-specific cumulative incidence functions using time-dependent weights have been first prepared and the weights incorporated to account for the competing events[26]. On such a novel dataset, the Cox proportional hazards model has been tested[27].

Table 6 shows the coefficients for the hazard to observe a civil citation. Results confirm the previous findings. An increase in either the technological or geographical scope, or the number of inventors, significantly increases the likelihood to observe a civil spillover compared to a military one.

[Table 6 here]

The country-level effects are again significant with respect to the baseline represented by the rest of the world. The time to observe a dual use is on average shorter when the inventions are developed in the US and this holds true even when comparing it also with the time to receive a military citation. The opposite finding, a negative correlation, emerges for the Russian Federation.

5.3 Domestic and international dimension

The results of the previous analyses indicate a different incidence of dual use cases among countries. Here we extend the investigation on knowledge spillovers to the civil sector comparing subsequent civil applicants located in the same country of origin of the military patent (i.e., domestic spillover) with foreign ones (i.e., cross-boundary or international spillover).

The time to receive an international civil citation is longer than for a domestic one (table 3). The result is not surprising, since it is reasonable that on average it takes more time for an invention to cross country borders and become international. Such a piece of evidence is consistent with the extant literature on the geographic clustering of knowledge flows as well as with the finding that localization tends to fade over time (Jaffe et al, 1993). However, this result might be also partly driven by the so-called *home bias* in citation practices (Bacchiocchi and Montobbio, 2010), i.e., the tendency of patent examiners to reference documents that are localized at the country level.

We also uncover a marked heterogeneity across technology fields. In fields such as *Organic fine chemistry* and *Chemical engineering*, the first international civil spillover occurs on average one year after the domestic one. On the contrary, areas such as *Basic materials chemistry*, *Other special machines including weapons and ammunition*, *Textile and paper machines*, *Macromolecular*

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[25] More information is available online at https://pclambert.net/software/stcrprep (last accessed in November 2019).

[26] We used the *stcrprep* routine with the latest version of Stata.

[27] The *stcox* routine has been employed.

chemistry, polymers, and *Machine tools* are characterised by an average difference of few months (5.0, 4.9, 4.5, and 2.8 months respectively).

Although the domestic dual use seems to occur earlier than the international one, civil spillovers show wider geographical coverage than military ones. In fact, dual use inventions are cited by patents filed on average in 2.3 countries whereas military inventions only in 1.4.

Table 7 shows the results of a set of competing-risks models that compare the geographical extent of the civil spillover. The employed procedure and the model specification are similar to the analysis in the previous section but, in this case, the competing events are the occurrence of domestic and non-domestic civil citations (i.e., international spillovers).

[Table 7 here]

In the sample, domestic civil citations are more likely to occur than non-domestic ones. Such a difference is particularly pronounced for inventions with a US priority. Moreover, patent families with a broader technical scope or with a larger team of inventors have on average a higher likelihood of receiving a domestic civil citation with respect to a non-domestic one. Priority interval dummies suggest the presence of a decreasing trend of domestic spillovers.

6 Conclusion

In this work, we have introduced a methodology to identify military innovation from patent data and measure knowledge spillover to civilian applications. In line with the previous literature (Watkins, 1990; Molas-Gallart, 1997; Oltmann, 2015), we have defined these cases as dual use. The defence and security industries develop complex cutting-edge technologies which might bring deep changes and push forward the technological edge of civilian applications. The study of dual use technologies can possibly help to improve our current understanding of the knowledge diffusion mechanisms related to government R&D investment in defence and security.

Our methodology to identify military innovation builds on previous approaches proposed in the literature that rely mainly on the technological codes contained in patent documents. We extend them by considering the nature of the patent applicants and by performing keyword searches in the patent text fields. This allows us to enlarge the scope of the analysis by expanding the pool of military innovations well beyond weapons and ammunition. In the empirical framework, dual use inventions are operationalised as military patent families that have received a forward citation from a civil patent. Several econometric models were employed to cope with the characteristics of the sample and the inevitable truncation introduced by the time needed for the first citation to occur.

Our analyses show that military innovations with a broader technology scope are more likely to become dual, confirming that redeployability across technological sectors is a positive element for the generation of civil spillovers. Concerning complexity, we find that larger teams of inventors are more likely to be involved in dual use inventions, thus suggesting that complexity is not a limiting factor to the civilian application of defence-related patents. The employed measure of innovation value, that is the geographical scope, is also positively related to dual use even when controlling for patent age and citation patterns. The collected evidence uncovers a marked heterogeneity of dual use cases across technological domains. Interestingly, the largest military field in the sample, which includes inventions related to weapons and ammunition, shows very limited spillovers to civil applications. This indicates that investment in traditional defence fields is less likely to foster subsequent civil developments of general interest. On the contrary, military inventions related to both medical technology and electrical engineering are those with the highest potential for contributing to the advancement of the civilian knowledge base. The results show that the incidence of dual use is decreasing over time. This finding holds even when considering the citation dynamics and controlling for geographical and technological variables. Furthermore, the knowledge flows inside the perimeter of military technologies are faster than those crossing the boundary and entering the civil domain. Such a result points in the opposite direction from the case study developed by Chakrabarti et al. (1993) which focused on *McDonnell Douglas* during the years from 1975 to 1988. According to that study, military companies were a closed club with slower spillovers in the defence sector while knowledge transfer to non-defence related firms seemed more effective[28]. Our findings suggest that either military technologies are less likely to be employed in civilian applications during recent years or that spillovers take more time to occur. The increase in specialization of defence-related innovations and the rising technological complexity might be potential explanatory factors. Too little attention has been paid to the role of defence-related R&D investments and innovation within the national innovation systems (Mowery, 2009). In the paper, we uncover a high heterogeneity in both dual use and the spillovers between countries with significant differences between the countries of origin of the defence innovations. The share of dual use cases is higher in the US where civil spillovers occur faster and are more likely to fall within the national borders than become international. On the opposite side of the spectrum is the Russian Federation where dual use is a limited phenomenon. This evidence suggests that spillovers from military to civil innovation depend on the approach of a country to military R&D funding. Furthermore, dual use cases occur more often for civil applications in the same country than abroad, suggesting limited knowledge spillovers among countries. Our results seem to indicate that the efforts made by the EU to create an integrated defence and security market may have relevant second-order effects on the innovativeness of the civil sector. These consequences might be particularly valuable for technological fields involving higher R&D costs per invention (e.g., biotechnology) or that are closer to basic research. The message for policymakers is that the overall knowledge spillovers are expected to be higher when military R&D is targeted at multi-purpose inventions that are developed in a distributed innovative environment.

Our analysis is not exempt from limitations. The identification of innovative activities related to the defence industry cannot be determined with absolute certainty since the description contained in the patent documents does not necessarily define its military or civilian use. We partially address this issue by focusing on firms with a clear military focus and integrating keywords and IPC codes in our search queries. We also recognise that neither all innovations are patented, nor a civilian use of a patented military invention is necessarily worth a new patent application in terms of technical novelty or economic profitability. Future research could focus on specific countries and exploit additional data sources for the identification of defence patents, such as the government interest statements for US-granted patents. Finally, although our operationalization based on forward citations is consistent with the ultimate meaning of dual use technologies, it introduces further limitations. The likelihood of receiving a citation can be different across the offices of filing due to differences in patent law (e.g., the so-called *duty of candor* at the UPSTO and a similar obligation at the JPO) and examiner practices. Our empirical approach sought to address these issues by considering the geographical scope and

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[28] It is necessary to note that the sample in the work of Chakrabarti et al. (1993) was much smaller than ours and only 37% of the patent assignees were categorised as civil or military entities.

applying a competing event survival analysis. Future studies might extend our research in several directions.

The use of patent citations as proxies of knowledge spillovers should account for biases introduced by the specificities of the patent application process. In particular, given that citations to the prior art added by patent examiners or attorneys could refer to documents unknown to the inventors of the citing patents (Jaffe, 2000), they indicate a circumstance in which spillovers may not have occurred. Scholars might consider the source (i.e., applicants versus patent examiners) of the received citations to better measure knowledge spillovers, although this will reduce the POs that can be considered (e.g., this information is not yet available at the EPO). Also, emphasis could be shifted to firm-level kind of analyses. Further evidence can be derived by matching disambiguated patentee names to financial or R&D data regarding the impact that several idiosyncratic characteristics of the organization where the innovation activities have been carried out (e.g., age, industry, location, size, ownership, etc.) have on the likelihood of generating spillovers from the military to the civil sectors and the specific features of the developed dual use technologies.

7 References

Acosta, M., Coronado, D. and Marín, M. R. (2011). Potential dual-use of military technology: does citing patents shed light on this process? *Defence and Peace Economics*, vol. 22, no. 3, pp. 335–349.

Acosta, M., Coronado, D., Ferrandiz, E., Marín, M. R. and Moreno, P. J. (2018). Patents and dual-use technology: an empirical study of the world's largest defence companies. *Defence and Peace Economics*, vol. 29, no. 7, pp. 821–839.

Acosta, M., Coronado, D., Marín, M. R. and Prats, P. (2013). Factors affecting the diffusion of patented military technology in the field of weapons and ammunition. *Scientometrics*, vol. 94, no. 1, pp. 1–22.

Acosta, M., Coronado, D., Ferrándiz, E., Marín, M. R. and Moreno, P. J. (2020). Civil-military patents and technological knowledge flows into the leading defense firms. *Armed Forces and Society*, 46(3), 454-474.

Acs, Z. J., Audretsch, D. B., Lehmann, E. E. and Licht, G. (2017). National systems of innovation. *The Journal of Technology Transfer*, vol. 42, no. 5, pp. 997–1008.

Alic, J. A., Branscomb, L. M., Brooks, H., Carter, A. B. and Epstein, G. L. (1992). *Beyond spinoff: military and commercial technologies in a changing world*. Harvard Business Press.

Avadikyan, A. and Cohendet, P. (2009). Between market forces and knowledge-based motives: the governance of defence innovation in the UK. *The Journal of Technology Transfer*, vol. 34, no. 5, pp. 490–504.

Avadikyan, A., Cohendet, P. and Dupouët, O. (2005). A study of military innovation diffusion based on two case studies. In: Llerena, P. and Matt, M. (Eds.), *Innovation Policy in a Knowledge-based Economy*. Springer, pp. 161–189.

Bacchiocchi, E. and Montobbio, F. (2010). International knowledge diffusion and home-bias effect: do USPTO and EPO patent citations tell the same story? *Scandinavian Journal of Economics*, vol. 112, no. 3, pp. 441–470.

Bellais, R. and Guichard, R. (2006). Defense innovation, technology transfers and public policy. *Defence and Peace Economics*, vol. 17, no. 3, pp. 273–286.

Bennett, S. (1983). Log-logistic regression models for survival data. *Journal of the Royal Statistical Society*, vol. 32, no. 2, pp. 165–171.

Bresnahan, T. F. and Trajtenberg, M. (1995). General purpose technologies: engines of growth'? *Journal of Econometrics*, vol. 65, no. 1, 83–108.

Bukkvoll, T., Malmlöf, T. and Makienko, K. (2017). The defence industry as a locomotive for technological renewal in Russia: are the conditions in place? *Post-Communist Economies*, vol. 29, no. 2, pp. 232–249.

Burmaoglu, S. and Sarıtas, O. (2017). Changing characteristics of warfare and the future of military R&D. *Technological Forecasting and Social Change*, vol. 116, no. C, pp. 151–161.

Caviggioli, F., De Marco, A. and Scellato, G. (2018). *Assessing the innovation capability of EU companies in developing dual use technologies*. Joint Research Centre.

Chakrabarti, A. K. and Dror, I. (1994). Technology transfers and knowledge interactions among defence firms in the USA: an analysis of patent citations. *International Journal of Technology Management*, vol. 9, no. 5–7, pp. 757–770.

Chakrabarti, A. K., Dror, I. and Eakabuse, N. (1993). Interorganizational transfer of knowledge: an analysis of patent citations of a defense firm. *IEEE Transactions on Engineering Management*, vol. 40, no. 1, pp. 91–94.

Chesnais, F. (1993). The French national system of innovation. In: Nelson, R. R. (Ed.), *National Innovation Systems: a Comparative Analysis*. Oxford University Press, pp. 192–229.

Clark, C. V. (1976). Obsolescence of the patent literature. *Journal of Documentation*, vol. 32, no. 1, pp. 32–52.

Cowan, R. and Foray, D. (1995). Quandaries in the economics of dual technologies and spillovers from military to civilian research and development. *Research Policy*, vol. 24, no. 6, pp. 851–868.

De Marco, A., Scellato, G., Ughetto, E. and Caviggioli, F. (2017). Global markets for technology: evidence from patent transactions. *Research Policy*, vol. 46, no. 9, pp. 1644–1654.

Enger, S. G. (2013). *Dual-use technology and defence-civilian spillovers: evidence from the Norwegian defence industry*. University of Oslo.

European Commission (2013). *Towards a more competitive and efficient defence and security sector*.

European Commission (2017a). *Reflection paper on the future of European defence*.

European Commission (2017b). *White paper on the future of Europe: reflections and scenarios for the EU27 by 2025*.

European Commission (2017c). *Horizon 2020 work programme 2018–2020: leadership in enabling and industrial technologies*. Part 5. European Commission Decision C(2017)7124 of 27 October 2017. Available at https://ec.europa.eu/programmes/horizon2020/sites/horizon2020/files/h2020-wp1820-leit_en.pdf.

Evangelista, R., Meliciani, V. and Vezzani, A. (2018). Specialisation in key enabling technologies and regional growth in Europe. *Economics of Innovation and New Technology*, vol. 27, no. 3, 273–289.

García-Estévez, J. and Trujillo-Baute, E. (2014). Drivers of R&D investment in the defence industry: evidence from Spain. *Defence and Peace Economics*, vol. 25, no. 1, pp. 39–49.

Gkotsis, P. and Vezzani, A. (2020). The price tag of technologies and the unobserved R&D capabilities of firms. *Economics of Innovation and New Technology*, pp. 1–23.

Griliches, Z. (1979). Issues in assessing the contribution of research and development to productivity growth. *The Bell Journal of Economics*, vol. 10, no. 1, pp. 92–116.

Griliches, Z. (1990). Patent statistics as economic indicators: a survey. *Journal of Economic Literature*, vol. 28, no. 4, pp. 1661–1707.

Hall, B., Helmers, C., Rogers, M. and Sena, V. (2014). The choice between formal and informal intellectual property: a review. *Journal of Economic Literature*, vol. 52, no. 2, pp. 375–423.

Harhoff, D., Scherer, F. M. and Vopel, K. (2003). Citations, family size, opposition and the value of patent rights. *Research Policy*, vol. 32, no. 8, pp. 1343–1363.

Hartley, K. (2006). *The industrial and economic benefits of Eurofighter Typhoon*.

Jaffe, A. B., Trajtenberg, M. and Henderson, R. (1993). Geographic localization of knowledge spillovers as evidenced by patent citations. *The Quarterly Journal of Economics*, vol. 108, no. 3, pp. 577–598.

Jaffe, A. B., Trajtenberg, M. and Fogarty, M. S. (2000). Knowledge spillovers and patent citations: evidence from a survey of inventors. *American Economic Review*, vol. 90, no. 2, pp. 215–218.

Jaffe, A. B. and De Rassenfosse, G. (2019). Patent citation data in social science research: overview and best practices. In *Research Handbook on the Economics of Intellectual Property Law*. Edward Elgar Publishing.

James, A. and Teichler, T. (2014). Defence and security: new issues and impacts. *Foresight*, vol. 16, no. 2, pp. 165–175.

Jovanovic, B. and Rousseau, P. L. (2005). General purpose technologies. In: Aghion, P., Durlauf, S.N. (Eds.), *Handbook of Economic Growth*, Elsevier, vol. 1., pp. 1181–1224.

Kepe, M., Black, J., Melling, J. and Plumridge, J. (2018). *Exploring Europe's capability requirements for 2035 and beyond*. European Defence Agency.

Kim, D. H., Lee, B. K. and Sohn, S. Y. (2016). Quantifying technology: industry spillover effects based on patent citation network analysis of unmanned aerial vehicle (UAV). *Technological Forecasting and Social Change*, vol. 105, no. C, pp. 140–157.

Klein, H. (2001). Technology push-over: defense downturns and civilian technology policy. *Research Policy*, vol. 30, no. 6, pp. 937–951.

Lazaric, N., Mérindol, V. and Rochhia, S. (2011). Changes in the French defence innovation system: new roles and capabilities for the Government Agency for Defence. *Industry and Innovation*, vol. 18, no. 5, pp. 509–530.

Lee, B. K. and Sohn, S. Y. (2017). Exploring the effect of dual use on the value of military technology patents based on the renewal decision. *Scientometrics*, vol. 112, no. 3, pp. 1203–1227.

Lipsey, R.G., Bekar, C. and Carlaw, K. (1998). What requires explanation? In: Helpman, E. (Ed.), *General Purpose Technologies and Economic Growth*. Massachusetts Institute of Technology Press.

Lundvall, B. Å. (2007). National innovation systems: analytical concept and development tool. *Industry and Innovation*, vol. 14, no. 1, pp. 95–119.

Lybbert, T. J. and Zolas, N. J. (2014). Getting patents and economic data to speak to each other: an algorithmic links with probabilities approach for joint analyses of patenting and economic activity. *Research Policy*, vol. 43, no. 3, pp. 530–542.

Maclin, H. M., Hauser, A. A. and Rakowski, W. (1994). *Dual-use ensures technology cross over*.

Martí Sempere, C. (2018). What is known about defence research and development spill-overs? *Defence and Peace Economics*, vol. 29, no. 3, pp. 225–246.

Molas-Gallart, J. (1997). Which way to go? Defence technology and the diversity of dual-use technology transfer. *Research Policy*, vol. 26, no. 3, pp. 367–385.

Morales-Ramos, E. (2002). Defence R&D expenditure: the crowding-out hypothesis. *Defence and Peace Economics*, vol. 13, no. 5, pp. 365–383.

Mowery, D. C. (2009). National security and national innovation systems. *The Journal of Technology Transfer*, vol. 34, no. 5, pp. 455.

Mowery, D. C. (2010). Military R&D and innovation. In: Hall, B. H. and Rosenberg, N. (Eds.), *Handbook of the Economics of Innovation*. Elsevier, pp. 1219–1256.

Mowery, D. C. and Langlois, R. N. (1996). Spinning off and spinning on(?): the federal government role in the development of the US computer software industry. *Research Policy*, vol. 25, no. 6, pp. 947–966.

Mowery, D. C. and Rosenberg, N. (1991). *Technology and the pursuit of economic growth*. Cambridge University Press.

Nelson, R. R. (1993). *National innovation systems: a comparative analysis*. Oxford University Press.

OECD (2009). *Patent statistics manual*. Organization for Economic Co-operation and Development Publications.

Oltmann, S. (2015). Dual use research: investigation across multiple science disciplines. *Science and Engineering Ethics*, vol. 21, no. 2, pp. 327–341.

Ram, R. (1995). Defence expenditure and economic growth. In: Hartley, K. and Sandler, T. (Eds.), *Handbook of Defence Economics*. Elsevier, pp. 251–274.

Rosenberg, N. and Trajtenberg, M. (2004). A general-purpose technology at work: the Corliss steam engine in the late-nineteenth-century United States. *The Journal of Economic History*, vol. 64, no. 1, pp. 61–99.

Ruttan, V. W. (2006). *Is war necessary for economic growth? Military procurement and technology development*. Oxford University Press.

Scherrer, W. (2020). How general-purpose technologies trigger long waves of economic development and thereby generate diversities of innovation. *UCJC Business and Society Review*, no. 65, pp. 36–49.

Schmid, J. (2018). The diffusion of military technology. *Defence and Peace Economics*, vol. 29, no. 6, pp. 595–613.

Serfati, C. (2000). The place of the French arms industry in its national system of innovation and in the governmental technology policy. In: Reppy, J. (Ed.), *The Place of the Defense Industry in National Systems of Innovation*. Cornell University Press, pp. 71–95.

Smith, B. G. (1994). Civil and military space in Europe: an industrial perspective. *Space Policy*, vol. 10, no. 2, pp. 91–94.

Te Kulve, H. and Smit, W. A. (2003). Civilian–military co-operation strategies in developing new technologies. *Research Policy*, vol. 32, no. 6, pp. 955–970.

Teece, D. J. (2018). Profiting from innovation in the digital economy: enabling technologies, standards, and licensing models in the wireless world. *Research Policy*, vol. 47, no. 8, 1367–1387.

Trippe, A. (2015). *Guidelines for preparing patent landscape reports*. World Intellectual Property Organization.

van Zeebroeck, N. and van Pottelsberghe de la Potterie, B. (2011). The vulnerability of patent value determinants. *Economics of Innovation and New Technology*, vol. 20, no. 3, pp. 283–308.

Vekstein, D. and Mehrez, A. (1997). Technology policy and defense conversion in Israel, 1967–1995. *The Journal of Technology Transfer*, vol. 22, no. 1, pp. 47–56.

Watkins, T. A. (1990). Beyond guns and butter: managing dual-use technologies. *Technovation*, vol. 10, no. 6, pp. 389–406.

8 Appendix

[Table A.1 here]

[Table A.2 here]

[Table A.3 here]

8.1 Robustness tests

[Table A.4 here]

[Table A.5 here]

[Table A.6 here]

[Table A.7 here]

[Table A.8 here]