Patents and Dual-use Technology: An Empirical Study of the World's Largest Defence Companies

Acosta, Manuel and Coronado, Daniel and Ferrándiz, Esther and Marín, M. Rosario and Moreno, Pedro J.

Department of Economics. University of Cadiz

2018

Patents and Dual-Use Technology: An Empirical Study of the World's Largest Defence Companies[1]

Manuel Acosta✉
Daniel Coronado
Esther Ferrandiz
M. Rosario Marin
Pedro J. Moreno

Departamento de Economía General, University of Cadiz, Cadiz, Spain

Abstract: This paper examines the generation of technological knowledge by leading companies in the defence industry. In particular, we test whether the characteristics of large defence companies are related to both the production of different types of patents (civilian, military and mixed), and the generation of dual-use technologies. To explore these links, we rely on economic data for the top-100 defence companies from the Stockholm International Peace Research Institute (SIPRI) database, and patent information from the Worldwide Patent Statistical Database (Patstat). Our results show that the relationship between the production of civilian patents and the size of the company is positive and significant. However, this relationship does not hold for the production of military patents. Furthermore, the military commercial profile is unrelated to the generation of military patents. Regarding the involvement in dual-use technologies, firms engaged in dual-use are those with higher military sales, a greater number of employees and a larger number of patents (civilian, military and mixed) than those not engaged in dual-use. Furthermore, we found a skill effect (more involvement in dual-use per employee) in European firms compared to US firms. These findings help to identify which firms should be targeted by government policies if increasing dual-use technologies becomes a political objective.

Keywords: dual-use technologies; patents; patent citations; large defence firms; technological knowledge

---

[1] Final version available at http://dx.doi.org/10.1080/10242694.2017.1303239

Acosta, M., Coronado, D., Ferrandiz, E., Marin, M. R., & Moreno, P. J. (2018). Patents and Dual-use Technology: An Empirical Study of the World's Largest Defence Companies. *Defence and Peace Economics*, *29*(7), 821-839.

✉ manuel.acosta@uca.es

Introduction

The motivation for the analysis of dual-use technologies lies in obtaining an additional return from military Research and Development expenditure (R&D), other than defence purposes. As Mowery (2012) argues, defence R&D investment has influenced innovation in the civilian sector of several OECD nations. The growing importance of dual-use and civilian-origin technologies, along with changing national security requirements and European cuts in defence research budgets, has changed the dynamics of defence technological innovation (James 2009). In this respect, dual-use policies, for instance, those focused on easing technology transfers between military and civilian markets, are of increasing importance in the knowledge-based economy (Mérindol and Versailles 2010).

Several studies have analysed the potential dual-use of defence technologies; some from a geostrategic perspective, dealing with differences among blocs or countries (MolasGallart 2002; Hartley 2003; James 2006); others addressing a single firm and how it organizes and manages R&D resources (Kulve and Smit 2003; Avadikyan, Cohendet and Dupouët 2005; Venturini, Verbano and Matsumoto 2013). In this research, we explore the role of the world's largest companies in the generation of technological knowledge, and the production of dual-use technologies. Furthermore, we analyse the links between the production of technology and dual-use, and the companies'
characteristics.

The paper contributes to the empirical literature by offering a new perspective from the output side (patents) and by aiming at the largest firms. The reasons for bringing big defence companies into focus are twofold. First, the defence industry, particularly in the USA and Western Europe, is led by a small number of very large firms (integrators) that employ state-of-the-art technologies and sell most of their production to their own governments (Golde and Tishler 2004; Shefi and Tishler 2005; Matelly and Lima 2016). Therefore, large defence companies are an important part of the defence industry.[2] Second, there are several studies that have examined knowledge production and dual-use technologies at the firm level, but using non-quantitative methodologies or case studies. Aggregate quantitative analyses on dual-use are scarce, and among them, the company's perspective has been neglected. Our paper tries to fill this gap. To our knowledge only the papers by Acosta, Coronado and Marín (2011), Acosta et al. (2013), and more recently Meunier and Zyla (2016), examine the military-civilian flows of technology from a micro-quantitative view. These articles discuss the potential civilian use of the knowledge embedded in military technology by using patent citations. Our analysis differs from these studies in several aspects. First, we centre on the world's largest defence companies; second, these papers deal with the production of weapons and ammunitions, and we account for a wide range of military technologies.

Our main indicators to carry out the analysis consist of patents as a measure of production of technology by companies, and patent citations to capture the extent to which a civilian patent is based on military knowledge (and consequently can be identified as a dual-use technology). Our data contain economic information provided by the Stockholm International Peace Research Institute (SIPRI), and technological

[2] These firms account for a large part of the defence industry. For example, in the case of Europe, the study for the European Commission by Cauzic et al. (2009) estimated the direct employment in the European defence industry as about 1,172,200 employees (including not just the production of weapons, but a wide range of activities), and 31.75% of this figure was provided by prime contractors.

information from the Worldwide Patent Statistical Database (PATSTAT, Spring 2014 edition). On the grounds of a literature review, our main research question –which will be the basis of the hypotheses tested in the following sections– is: are large firms' characteristics related to the production of military knowledge and to involvement in dual-use technologies?

The answers to this question may cast some light on the relationships between the companies' characteristics and the production of different types of knowledge (civilian, military or mixed), which might guide policy makers and practitioners in two ways. On the one hand, governments have the capacity to influence the decisions to pursue dual military/civilian product lines (spin-off or spin-in effects) (Matelly and Lima 2016), and dual-use is still used to justify support for the defence industry in a period when it has lost some of its capacity to draw political backing (European Commission 2014; MartíSempere 2016). Therefore, in order to increase dual-use technologies, the identification of the relationships between companies' characteristics and the production of military/civilian technologies could help provide new clues on innovation policies in guiding what firms should be targeted. On the other hand, deepening the understanding of the relationships between companies' characteristics and the production of knowledge can benefit managers by enabling them to put forward strategic decisions and justify their economic defence activity in terms of social responsibility.

The remainder of the paper is organized as follows. In the next section, we define the concept of dual-use technology and we review the factors affecting the firms' involvement in this type of technology. Then, we put forward our hypotheses. The Methodology section is focused on the advantages and disadvantages of using patents and patent citations to measure technology, and how firms engaged in dual-use technologies can be identified. The next section describes the procedure followed to obtain our data. Results provide the answers to the research questions by relating the firms' characteristics to the generation of patented knowledge and dual-use technologies. Conclusions are drawn at the end of the paper.

Literature Review and Hypothesis

This section is divided into two parts. Firstly, we review the concept of dual-use technology, and highlight the main literature that has identified the factors affecting the firms' involvement in dual use technologies. Secondly, we put forward the hypotheses that we will be tested in the Results Section.

Literature review

The term 'dual-use' was originally coined in discussions about technology transfer between civilian and military applications. Dual-use technology can be defined as that developed and used both by the military or space sector and the civilian sector (Cowan and Foray 1995) or, in other words: 'Technology that has both military and commercial applications' (Alic et al. 1992, 4). Wallin (2012) explained that on some occasions the term dual-use overlaps with the term *spin-off*. Meunier and Zyla (2016) also comment on this coincidence of the terms in a brief review of the dual-use concept. Molas-Gallart (1997) argued that dual use is a broad term and includes the industrial advantage of R&D efforts that goes beyond the initial objectives. Then, dual-use technology can be understood in two directions: military technology that is used for civilian innovation (*spin-off*) or vice versa (*spin-in*). Despite evidence of the adoption of civilian technology for military purposes (Avadikyan, Cohendet and Dupouët 2005; Cowan and Foray 1995; Mowery 2010), the main focus has been on how military innovations spill over into civilian use (Acosta, Coronado and Marín 2011). The motivation for this choice is the effects of defence related R&D investments on civilian innovation. Thus, an underlying reason of the analysis of spin-off processes in defence and space is the activation of the technology transfer between these sectors and other industries. The main aim is to identify new applications and business opportunities, promoting additional skills and fostering innovation processes in the whole industrial system (Amesse et al. 2002; Venturini, Verbano and Matsumoto 2013). Trajtenberg (2006) raised a different argument to stress that R&D is required to provide advanced means for intelligence and for target protection with the new terrorism era after the 9/11 attacks, which involves emulating human sensory perceptions through computerized sensory interfaces, and increasing the ability to analyze big data. These technologies have military, but also civilian applications (dual-use), and include private firms as developers and a private market.

Some notable examples of civilian technologies that trace their origins to military R&D are commercial aerospace technology (Mowery and Rosenberg 1982), the Internet (Mowery and Simcoe 2002) and the global positioning system (Larsen 2001). Similar spin-off processes have been described in the space industry (Amesse et al. 2002; Venturini, Verbano and Matsumoto 2013). Although traditionally the spin-off effect from the military to the civilian sector was the centre of attention, now this pattern has changed. Most military equipment stems from highly sophisticated commercial technology, and governments are interested in highlighting areas where military and non-military capability needs are similar and identifying the potential for synergies

(Stowsky 2004; European Commission 2014).

With respect to the second question, some factors affecting dual-use technologies can be identified. There are many case studies, but the quantitative evidence is rare. Cowan and Foray (1995) argued that in the first development stage of a technology there is more room for experimental variety, and as a consequence, dual-use technologies are more likely in the early stage of development. As technologies mature, civilian and military requirements often tend to diverge, thus reducing the potential for dual-use technologies (Mowery 2012). Kulve and Smit (2003) analysed dual-use strategies in the development of an advanced battery in the Netherlands, focusing on the co-operation between civilian and military actors. Their results showed that potential duality appeared at a later stage of the development phase, and that the participation of the 'dual actor' open a window of opportunity for the involved actors to cooperate for *joint development* of both civilian and military applications. Avadikyan, Cohendet and Dupouët (2005) based on interviews with industrial managers of two firms involved in complex military projects (Thomson-CSF Airsys and Matra BAE Dynamics) analysed the factors affecting the *spin-off* process of military technology. From their research, the authors identified four enabling factors: 1) the technological variety, in the sense of technologies stemming from different sectors; 2) *Spin-in* or two-way diffusion, since it brings the defence and civilian sectors closer; 3) military functionality close to the needs of civilian sectors; 4) the tendency in defence projects to sub-contract work to SMEs, which are often engaged in civilian activities. Mowery (2010, 1231) found that US defence firms for which the highest proportion of revenues derived from military sales, tended to specialise in military markets, reducing their motivation for civilian applications. Apart from the features of the technology, Venturini, Verbano and Matsumoto (2013) underline other elements that can influence the transfer generated by spin-offs in the space industry, such as those related to the characteristics of the agents involved in the transfer process (knowledge of potential markets for the transfer; R&D competences, knowledge, and the homogeneity of the technical culture; relational abilities and motivational factors of support and resistance; economic convenience and availability of financial resources). Brzoska (2006) suggested that differences in objectives in technological innovation between military and civilian sectors are also more likely as one nears the development of weapons. This is confirmed by the results of Acosta, Coronado and Marín (2011). On the other hand, dual use technologies will be more likely for firms with civilian and military revenues.

Acosta, Coronado and Marín (2011) and Acosta et al. (2013) contribute to this topic by using patent citations to identify spin-off effects from military to civilian technologies. They found that there is a geographical component in the dual-use pattern, with British, French and US military patents the most cited for civilian uses, while Japan is the greatest dual user. They also found that the previous technological experience of the citing company/institution, as measured by the number of owned patents, is an explanatory factor in dual-use technologies. All in all, these papers suggest that both technological and commercial factors determine the dual-use of technology. Meunier and Zyla (2016) construct two samples of US firms, one civilian and the other from the defence sector. By using patent information and estimating an econometric model, they conclude that there is a different pattern in the effect of the generality and originality of the innovative activities on the growth of civilian and defence companies.

Hypotheses

The above literature has stressed some relevant factors affecting the production of dualuse technologies, such as the features of the transferred technology, the cooperation, and the characteristics of the agents involved in the process. However, this evidence is mostly qualitative and based on case studies. In the following paragraphs, we put forward several hypotheses –that can be tested quantitatively– linking the companies' characteristics to the production of civilian, military and mixed knowledge, and to the engagement in dual-use technologies. The first two hypotheses focus on the production of patented technologies and its relationship with the size and the technological profile of the company. The third hypothesis relates the production of dual use technologies to companies' characteristics. Finally, the fourth hypothesis raises possible significant differences in the production of knowledge and dual-use between Europe and the USA.

Firm size has been one traditional explanatory factor in most innovation studies, and there is a huge range of literature on this topic (for example, Acs and Audretsch 1987; Satarelli and Sterlacchini 1990; Rogers 2004). Overall, there is not clear evidence that innovative capacity increases with firm size. The effect of the size varies depending on the sector, and there is not much evidence in the defence industry. Large firms have greater ability to secure funding for risky projects, given capital market imperfections, and this is one of the arguments put forward in supporting the hypothesis that innovation expenditure increases more than proportionately with the firm size (see review by Becker, 2015). For example, Audretsch et al. (2002) point out that the aircraft sector is one of the areas in which large firms might have innovative advantages. This reasoning leads to the first hypothesis:

H.1. Large firms find it easier than small firms to have access to resources or to internally generate the funds that are necessary to run large defence R&D programs. As a consequence, a positive and significant relationship between the size of the defence company and the production of patented technology is expected.

The sale of arms is a business activity that characterizes the defence industry. Most of the firms in the sector sell both arms and other products with civilian uses (such as aircraft, transport and electronic equipment). When the firm addresses different technological activities –military and civilian–, coordination costs may increase because more diversified firms are more likely to encounter difficulties in combining mature, or exploitative, technologies with explorative trajectories (Granstrand and Oskarsson 1994; Leten, Belderbos and Van Looy 2007). Focusing on a small number of areas through specialization can also be beneficial in increasing learning and knowledge accumulation (Chiu et al. 2010). Some previous research has made use of arms sales as an indicator to look into the sector at the firm level. For example, Martin, White and Hartley (1996) applied the ratio of armament sales and turnovers to identify the extent to which a company is dedicated to the defence sector and to determine its specific business characteristics. Goyal, Lehn and Racic (2002) analysed the relationship between sales and the differences in debts of a group of North American defence firms; their results complement other studies that have found cross-sectional relations between proxies for growth opportunities and leverage variables. Belin and Guille (2008) use data on French firms to examine the impact of defence dependence on firms' financial structure. Wang, Shyu and Chou (2012) argue that the origin of the greater productivity of North

American defence firms can be explained by the sales in their own country, in contrast to European companies. In this paper, we use the share of arms sales in the company's turnover to test the following hypothesis linking the firm's involvement in arms production and technological production:

H.2. Firms focused on military sales produce military technology more efficiently because they can reap benefits from specialization such as learning, knowledge transfer and accumulation. Then, it is expected that greater military commercial profile of the firm is associated with a greater production of military and mixed technological knowledge.

The next hypothesis is supported by the literature reviewed above, which underlines the relevance of the companies' characteristics (along with other factors) in the generation of dual use technologies (e.g. Kulve and Smit 2003; Avadikyan, Cohendet and Dupouët 2005; Venturini, Verbano and Matsumoto 2013):

H.3. Defence firms diverge in their objectives (some focus only on military markets, while others target both military and civilian markets), in size and in skills. As dual-use depends on attributes such as technological variety and functionality of the firm, different approaches to dual-use can be expected depending on the characteristics of the firms.

There is some research that has looked into the features and differences in the production of knowledge and the generation of dual-use technologies between US and Europe. For example, Hartley (2003) pointed at possible differences due to the specific characteristics of the markets (the US home market is much larger than the European).

Hartley (2008) suggests that in terms of sales and employment amongst the top five defence companies, the average US firm is some 1.7 times to twice the size of the top five EU firms, arguing that American companies are more competitive through achieving greater economies of scale, learning and scope. In this paper, we intend to test whether there are differences in the values of the technological variables, and the extent to which these differences are associated with the companies' characteristics. Apart from the previous background, two empirical facts inspire the next hypothesis. First, according to the data from the SIPRI, with one exception, the 20 largest defence companies in the world are located in the United States and Western Europe. Second, the combined share of the USA and Western Europe (mainly the UK, France, Germany, Italy, Sweden, Switzerland and Spain) in the world's military expenditure accounts for
75.64% in the period 2002-2011:

H.4. There are significant differences in the production of knowledge and the generation of dual-use technologies between US and Europe, and these differences are associated to the companies' characteristics located in each area.

Finally, Figure 1 presents a flow diagram showing the steps to test the hypotheses.

[Figure 1 near here]

Methodology

As depicted in Figure 1 above, the methodology used to quantify the production of knowledge and dual-use technologies relies on patents and patent citations. First, patents have been largely used as indicators of firm innovation. Advantages and disadvantages of patents can be found in Griliches (1990) and Archibugi (1992); different kinds of applications have been discussed, for instance, in Chakrabarti, Glismann and Horn (1992), Bellais and Guichard (2006) or Guillou et al. (2009). In this paper, we use the International Patent Classification (IPC) to identify the technological sector and the patents cited in the background, which will allow us to track knowledge flows across civilian and military sectors. Sectors F41 (weapons) and F42 (ammunition, blasting) in the IPC correspond to military sectors (Table 1). However, other technological IPC must be taken into account (Table 2). A discussion about this classification can be found in Acosta et al. (2013).

[Table 1 and Table 2 near here]

Using the IPC, and bearing in mind the objectives of this paper, we classify all patents applied for by defence firms into three categories:

- Military patent, when it only includes military IPC codes (Tables 1 and 2).
- Mixed patent: when it includes one or more military IPC codes (Tables 1 and 2), along with at least one non-military IPC code.
- Civilian patent: when it does not include any of the military IPC codes listed in Tables 1 and 2.

Second, patent citations have a long tradition in the economic literature to track knowledge flows across technological sectors. In simple words, citations in a patent (backward citation) refer to a piece of knowledge that has been useful in developing a particular patented invention. Thus, technological citations can be understood as an indicator of knowledge flows among sectors, institutions, firms or regions. More details on this methodology, its advantages and limitations can be found in Griliches (1990), Jaffe, Fogarty and Banks (1998), Jaffe, Trajtenberg and Fogarty (2000), Jaffe and Trajtenberg (2002), Acosta and Coronado (2003) and Breschi and Lissoni (2004). Following this line of reasoning, we use patent citations added by the inventor in the patent application as an indicator that the cited patent has contributed to the generation of the new technological knowledge.

As we highlighted in the literature review, the dual-use concept, as defined by Cowan and Foray (1995), refers to technologies that are developed and used by the civilian and military sector. Then it has a double meaning: technologies that are developed and used in the civilian sector and which later found a military use, and vice versa. In this paper, we limit the concept of dual-use to the one stemming from a technology initially developed for military applications that has been subsequently used in the civilian sector. Focusing on this type of *spin-off* effect from military to civilian technology allows us to test whether defence technologies, *per se*, can have a potential civilian use, which would provide more support for military R&D expenditures. A detailed discussion can be found in Acosta, Coronado and Marín (2011) and in Acosta et al. (2013).

Finally, we use simple procedures to test our hypotheses that do not involve the estimation of econometric models. Basically, the reason for this choice is twofold. First, this study is exploratory; we do not intend to obtain the precise effect of some variables on others, but only to advance significant correlations and differences in the production of military knowledge and dual use technology related to the firms' characteristics.

Second, the availability of data is very limited if we were to estimate a whole model in which we would need not only one explanatory factor, but also several control variables. Given this restriction, we explore the existence of a linear relationship between the production of military/mixed patents and size (and commercial profile) by using the *t-test* for testing the population correlation coefficient under H_0: $\rho = 0$. To test whether the production of patents and dual-use technologies differ significantly depending on the characteristics of the firms, we rely on standard mean difference tests, assuming that H_0 (standardized mean difference=0) was the null hypothesis to reject.

Data

Construction of the Data Set

To build our data set we have followed four steps:

1. First, we selected the defence firms based on the data published annually by the SIPRI for the top-100 defence firms in the world. This database covers the period 2000-2014 and includes firms with the highest volume of armament sales. It provides data on total sales, armament sales, total employment and profits of each firm[3]. It is important to stress that this information is not exclusively oriented towards the defence market. The top-100 includes firms like Airbus or BOEING, which dedicate a large amount of their business to the civilian market. The list of firms contains more than 100 firms as a consequence of entry/exit of firms,

[3] The SIPRI website (www.sipri.org) provides detailed information on the dataset and the definitions of the variables.

mergers of firms and acquisitions. Although the SIPRI data set includes information until 2014, we have ruled out the years 2012-2014 because it takes time for the data on patent applications to be updated and included in Patstat. An additional constriction is that the SIPRI data set does not contain information for all firms and all variables; for example, AAR Corp only shows data from 2009 and 2010, BAE Systems from 2002 to 2010, Nexter from 2007 to 2010 or MTU Aero Engines from 2004 to 2009. In order to enable comparisons, we calculated the average of the data for each firm, and therefore we finally have only one observation for each variable and firm. This also reduces the number of outliers in our data. We gathered data for 106 firms in this step. Finally, it should be borne in mind that there are other countries with a thriving defence industry that are not considered in our analysis because a lack of data (see for example, the paper by Lee and Yoon (2015), about the learning process of latecomers –South Korea, China, and Brazil– in military aircraft development). This is particularly true for China. Although several Chinese arms-producing companies are large enough to rank among the largest in the world, it has not been possible to include them because of a lack of accurate information.

2. Second, we retrieved information on patent applications of the top-100 firms in the period 2002-2011. By using the list of top defence firms obtained in step 1, we collected the number of patent applications to the European Patent Office between 2002 and 2011. This data set was built using raw patent data in Patstat (Spring 2014 edition). For this search, we build on the algorithm K.U. (kindly provided by the K.U. Leuven), which was extended to include all names of the firms. In this paper, we use EPO patents for two main reasons. First, it is expected

that European patents have higher technological relevance than those registered in national offices because they often involve higher application costs (Del Barrio-Castro and García-Quevedo 2005); second, in order to make international comparisons we want to avoid differences in patent citation practices across patent offices (e.g. for an comparison between UPSTO and EPO patents, see Bacchiocchi and Montobbio [2010]). Besides, we aim to avoid double counting of the same innovation, as sometimes a patent is first applied for to the national office and then to the international office.

From the 106 defence companies obtained in step 1, we finally count on 71, which are those having patent applications in the period of study[4]. Therefore, we focus on firms that generate patented technological knowledge. From these firms, we distinguish between those producing dual-use technologies and firms that are not engaged in dual-use. The excluded firms without patent applications are either firms that did not have any technological activity to grant patent protection, or companies that use other means to protect their technological breakthroughs.

3. Third, we classified patents into one out of the following three categories according to their IPC codes and following Acosta, Coronado and Marín (2011): civilian (only containing IPC codes classified as civilian) military (only containing IPC codes classified as military) and mixed (with military and civilian IPC codes).

[4] We also eliminated one firm for which the employment was 0, and another firm that did not have data for total sales.

4. Finally, in order to identify those technologies that can be classified as dual-use, we gathered information on citations in these patents to earlier patents (backward citations). Linking the classification of one patent (military, mixed or civilian) to the classification of the cited patents (military, mixed or civilian), we are able to identify the type of use of a particular technology. That is, we determine the involvement of the firm in dual-use by identifying when a civilian or mixed patent cites a military or a mixed patent.

Characteristics of the Defence Firms

Table 3 shows the descriptive statistics of the data set in the initial stage containing 106 defence firms, and the final selected group of 71 firms. Table 3 shows that the sample of firms is very heterogeneous in terms of total sales and armament sales, which implies that there are firms with a low participation in the military market, and firms that are only focused on armament sales. Differences remain by country, or by their military commercial profile (share of arms sales over total sales) (Table 4). At country level, it is noticeable that the US and trans-European firms show higher average arms sales than other countries. The US firms have more employees and more total sales than firms from other countries; however, they show a similar share of arms sales over the total; firms from Israel, Italy and UK are those with a higher average ratio.

[Table 3 and Table 4 near here]

Technological Knowledge of the Defence Firms

In this section, we firstly explore the patenting activity (civilian, military and mixed patents) applied for by defence firms. Although we have information until 2012, we graph the data until 2008 to avoid noise because, as explained above, the information from that date may not be reliable since it takes time to be recorded into Patstat. The evolution of the patenting activity of the defence industry (Figure 2) reveals an increasing technological innovation from 1980, but from 2000 this trend is stabilized. Although most patents from the defence industry are civilian, there is a greater activity in the application for patents classified as military (only containing IPC codes classified as military) and mixed (IPC codes military and civilian) in the last few years of the period.

[Figure 2 near here]

Focusing on the generation of technological knowledge (Tables 5 and 6), there is a great concentration of civilian patents in few firms (General Electric, Honeywell, EADS/AIRBUS, Hewlett Packard, etc), but there is not a clear relationship between the number of civilian patents and the number of military or mixed patents. Military patents are still more concentrated than civilian patents in firms like Rheinmetall, Raytheon, Nexter, Kraus-Maffei, Diehl or Saab.

[Table 5 and Table 6 near here]

Defence Firms and Dual-Use

Citations to other patents in the portfolio of each firm show the flows between technologies. The greatest part of knowledge flows (97.5%) is civilian-civilian (patents classified as civilian that cite only civilian patents). Only 2.5% of citations are from mixed and military patents, and 13% of those citations can be classified as dual-use (military citations used to support civilian inventions).

Table 7 shows firms that include the greatest number of citations to military patents in their civilian patents (dual-use) and the number of patents applied for by each firm.
Note that some firms like Rheinmetall cite more military than civilian patents. Compared to the flows of knowledge across patents, dual-use is much less frequent, and is restricted to a small number of firms, which suggests a certain level of propensity or skill of this kind of military use depends on firm characteristics. In this section, we address this issue by answering two main questions related to the links between the production of dual-use technologies and firm characteristics.

[Table 7 near here]

Results

Technological Knowledge Production and Firm Size (H.1)

We have used two indicators to measure the size of the defence company: the number of employees and arms sales. A first look at the data in Figure 3, which depicts four scatter plots between patents and employment (both in logarithms), shows that there is a close relationship between the number of employees of the company and the production of total and civilian patents. However, this pattern is less clear for military and mixed patents.

Our second indicator accounts for the arms sales of the company. Figure 4 presents the relationship between arms sales of all defence firms in our sample and the production of each type of knowledge. Note that the relationship between the sales of arms of the company and the production of civilian patents is positive, but again there is not a clear relationship between size, measured now as arms sales, and the production of military and mixed patents.

[Figure 3 and Figure 4 near here]

In order to identify how significant those relationships are, we present in Table 8 the coefficients of correlation between the size of the company –measured by the number of employees and arms sales– and the production of patented technological knowledge (all variables are in logarithms). These data show that there is a positive and significant relationship between firm size and the production of civilian patents (there is also a high significant correlation between size and the total number of patents, but this is meaningful because the majority of patents are civilian). The data also reveal a weak positive relationship between size –measured by arms sales– and the production of mixed patents. However, firm size and military patents are unrelated; the correlation is near zero, which suggests that there is no relationship between how large a firm is and the number of military patents that it produces. Overall, these results confirm the widespread assumption that the size of a particular firm is related to the firm's skill in generating new civilian technologies in general, but this does not hold when the technology has a military component.

[Table 8 near here]

Knowledge Production and Military Commercial Profile (H.2)

The scatterplots presented in Figure 5 show a negative relationship between the production of civilian patents and the military commercial profile of the firm, while the production of mixed and military patents and military commercial profile seem to be unrelated. Again, we have obtained the correlations to identify the magnitude of such relations. Table 9 confirms a negative and significant relationship between the military commercial profile and civilian patents, while that variable is uncorrelated with mixed and civilian patents. The first result is quite intuitive, suggesting that the more a company is focused on the military business, the less it is interested in producing civilian technologies. More surprising is the lack of a significant relationship between the intensity of a firm's focus on the military business and the production of military technologies, which can be explained by the use of other methods of protecting inventions different from patenting.

[Figure 5 and Table 9 near here]

Dual-Use Technologies and Companies' Characteristics (H.3)

In order to analyse the differences in dual-use technologies according to the business characteristics of the defence firms, we have performed a mean-difference test. Table 10 presents the results showing the mean of several business variables splitting into two groups: those firms involved in dual use and those firms that patent, but without engaging in dual-use. Our findings show that firms engaged in dual-use have higher total and military sales, a greater number of employees and more patents (civilian, military and mixed) than those not engaged in dual-use. The size of the company is the main variable that makes the difference between firms engaged in dual use and firms that are not. Note that the relationship is not only with the size of the firm, but also with its technological size (accounting for the number of patents). If we control for the size – dividing these variables by the number of employees of each firm– we obtain an indicator of technological productivity (number of patents per employee). Note that the differences remain and those firms engaged in dual use are not only the largest, but also the most technologically productive.

[Table 10 near here]

Differences Between Europe and the USA (H.4)

The majority of large defence firms are from European countries and from the USA, therefore it is worth testing the differences in the characteristics of the companies located on both sides. Table 11 shows the mean of several economic variables of European and American firms separating companies engaged in dual-use from those that are not. In the group of firms that are not engaged in dual-use (left part of Table 10), there are not significant differences between European and US firms, except in the average number of military patents, which is greater in Europe. If we control for the size, dividing the technological data by the number of employees (obtaining again an indicator of technological productivity), we find that European firms show a higher number of total patents and civilian patents per employee in the group of firms not engaged in dual use.

[Table 11 near here]

Looking at the group of firms involved in dual-use technologies, the differences are significant for some business variables (see the right part of Table 10); for example, sales figures for US companies are much higher than for the European firms, as is the number of employees. However, there are not significant differences for the technological variables (patents and dual use). Dividing these technological variables (total, civilian, mixed and military patents, and citations) by the number of employees of each firm, the results change dramatically. The differences are significant and the averages are always greater for European firms. This suggests that European firms engaged in dual use demonstrate greater technological productivity (a greater number of mixed and military patents per employee) than US firms. Furthermore, European firms show significantly more citations per employee than US firms.

Conclusions

The worldwide defence industry is composed of firms that produce for both civilian and military markets. In this paper, we have examined the types of technology (civilian, military and mixed) developed by the world's largest companies that account for a considerable part of the defence industry. Additionally, we have addressed the capacity of these companies to be involved in dual-use technologies by using patent citations. Our main objective focused on analysing the extent to which the technological production of the defence firms is linked to their business characteristics. In this respect, we have tested a series of hypotheses, the results of which are summarized as follows:

- *Production of technology and firm size.* The production of civilian patents is significantly linked to the size of the company. However, the generation of military and mixed patents is neither clearly related to the number of employees nor the arms sales of the company. This result points to a distinctive characteristic of the defence industry. In contrast to the civilian sector, in which contacts with clients and suppliers would produce flows of knowledge that might be useful for developing new technologies, the generation of military technologies seems to respond to different incentives.

- *Production of technology and military commercial profile*. The correlations show a negative and significant relationship between the military commercial profile (ratio between arms sales and total sales) and the production of civilian patents. This is an expected finding suggesting that firms focusing on military markets have little concern for producing civilian patents. What is surprising is the lack of correlation between the military commercial profile and the production of military patents, which indicates that the production of military or mixed patents is independent of the military specialization of the firm (in terms of arms sales).

- *Differences between firms engaged in dual-use technologies and firms that are not.* A mean-difference test shows that firms engaged in dual-use are those with higher military sales, a greater number of employees and a greater number of patents (civilian, military and mixed) than those not engaged in dual-use. This result suggests that it is not only the size of the firm that is relevant; what really matters for producing dual-use technologies is also its technological size (accounting for the number of patents). Our results also indicate that firms engaged in dual-use have some particular skills, because when we divide the number of patents by the number of employees, these firms present a higher number of total, civilian, mixed and military patents per employee compared to firms not involved in dual use. Then, we found both a size effect and a skill effect in the companies involved in dual-use technologies.

- *Differences between Europe and the USA.* In absolute terms, there are significant differences in the size of firms producing dual-use technologies between Europe and the USA. However, if we apply an indicator of technological productivity (dividing the number of patents by the number of employees of the company), a mean 't' test shows that European firms engaged in dual-use technologies have higher technological productivity (a greater number of mixed and military patents per employee) than US firms. Furthermore, European firms present more military citations per employee in their civilian patents than US firms. These results confirm the existence of an ability or skill effect, which was previously observed when we compared dualuse vs. non dual-use firms. This skill effect seems to favour European firms compared to American companies.

From a political viewpoint, our results provide some clues to practitioners. Firstly, governments determine the direction of defence and civilian technology through the public expenditure, and their support is a key factor in developing new innovative projects to seek cooperation opportunities in R&D. A clear example in the context of the European Union is in the recent Report from the Commission to the European Parliament focused on the implementation of a roadmap for a more competitive and efficient defence and security sector in Europe (European Commision, 2014), which includes several concrete actions to exploit the dual-use potential of research. In particular, the Commission intends to maximise synergies in both directions between the civil research of Horizon 2020 and defence research. In this respect, better knowledge of the characteristics of firms engaged in the production of different types of technologies and dual-use products may help identify what companies should be targeted.

Secondly, defence firms may be interested in communicating to their shareholders and to society, not only their figures as defence suppliers, but also their role as contributors of technologies that might become of civilian use. The incorporation of information about the dual-use of defence technology or the technological knowledge generated by a firm in its Corporate Social Responsibility (CRS) report could be useful in stressing their contribution to public ends (apart from security). This issue is particularly relevant because defence firms have been typically excluded from CSR (Halpern and Snider 2012).

Finally, some limitations should be acknowledged when interpreting our results. First, we counted on a sample of large firms and despite large companies being an important part of the defence business, the result cannot be extended to the whole defence industry. Second, this is a first exploratory study; our analysis only shows that companies' characteristics are related in a systematic way to the production of knowledge and generation of dual use, along with some differences between Europe and the US. However, this does not prove that the relationships are cause-and-effect relationships. Much further research is required to clarify the causal impacts of all variables involved in the process of developing new patents, or in the use of military knowledge with civilian ends.

References

Acosta, M., & Coronado, D. (2003). Science technology flows in Spanish regions: An analysis of scientific citations in patents. *Research Policy, 32*, 1783–1803.

Acosta, M., Coronado, D., & Marín, M. R. (2011). Potential dual use of military technology: Can patents shed light on it? *Defence and Peace Economics, 22*, 335–349.

Acosta, M., Coronado, D., Marín, R., & Prats, P. (2013). Factors affecting the diffusion of patented military technology in the field of weapons and ammunition. *Scientometrics, 94*, 1–22.

Acs, Z. J., & Audretsch, D. B. (1987). Innovation, market structure, and firm size. *The Review of Economics and Statistics, 69*(4), 567–574.

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

Amesse, F., Cohendet, P., Poirier, A., & Chouinard, J. M. (2002). Economic effects and spin-offs in a small space economy: The case of Canada. *The Journal of Technology Transfer, 27*(4), 339–348.

Archibugi, D. (1992). Patenting as an indicator of technological innovation: A review. *Science and Public Policy, 19*(6), 357–368.

Audretsch, D. B., Bozeman, B., Combs, K. L., Feldman, M., Link, A. N., Siegel, D. S., Stephan, P., Tassey, G., & Wessner, C. (2002). The economics of science and technology. *The Journal of Technology Transfer, 27*(2), 155–203.

Avadikyan, A., Cohendet, P., & Dupouët, O. (2005). A study of military innovation diffusion based on two case studies. In P. Llerena & M. Mireille (Eds.), *Innovation policy in a knowledge-based economy* (pp. 161–189). Berlin Heidelberg: Springer.

Barrio-Castro, T. D., & García-Quevedo, J. (2005). Effects of university research on the geography of innovation. *Regional Studies, 39*(9), 1217–1229.

Bacchiocchi, E., & Montobbio, F. (2010). International knowledge diffusion and home-bias effect: Do USPTO and EPO patent citations tell the same story? *The Scandinavian Journal of Economics, 112*(3), 441–470.

Becker, B. (2015). Public R&D policies and private R&D investment: A survey of the empirical evidence. *Journal of Economic Surveys, 29*(5), 917–942.

Belin, J., & Guille, M. (2008). Defence and firm financial structure in France. *Review of Financial Economics, 17*(1), 46–61.

Bellais, R., & Guichard, R. (2006). Defense innovation, technology transfers, and public policy. *Defence and Peace Economics, 17*(3), 273–286.

Breschi, S., & Lissoni, F. (2004). Knowledge networks from patent data: Methodological issues and research targets. *CESPRI Working Papers*. Milan: Universita L. Bocconi.

Brzoska, M. (2006). Trends in global military and civilian research and development and their changing interface. In *Proceedings of the International Seminar on Defence Finance and Economics* (pp. 1–23). New Delhi, November 13–15.

Cauzic, F., Colas, H., Leridon, N., Lourmi, S., & Waelbroeck-Rocha, E. (2009). A comprehensive analysis of emerging competences and skill needs for optimal

preparation and management of change in the EU defence industry. *Final Report, Eurostrategies,* 20.
Chakrabarti, A. K., Glismann, H. H., & Horn, E. -J. (1992). Defence and space expenditures in the US: An inter-firm analysis. *Defence Economics, 3*(2), 169–189.
Chiu, Y. -C., Lai, H. -C., Liaw, Y. -C., & Lee, T. -Y. (2010). Technological scope: Diversified or specialized. *Scientometrics, 82*(1), 37–58.
Cowan, R., & Foray, D. (1995). Quandaries in the economics of dual technologies and spillovers from military to civilian research and development. *Research Policy, 24*, 851–868.
European Commission. (2014). *A new deal for European defence: Implementation roadmap for communication COM (2013) 542 towards a more competitive and efficient defence and security sector.* COM 0387, June 2014.
Granstrand, O., & Oskarsson, C. (1994). Technology diversification in "MUL-TECH" corporations. *IEEE Transactions on Engineering Management, 41*(4), 355–364.
Golde, S., & Tishler, A. (2004). Security needs, arms exports, and the structure of the defense industry determining the security level of countries. *Journal of Conflict Resolution, 48*(5), 672–698.
Goyal, V. K., Lehn, K., & Racic, S. (2002). Growth opportunities and corporate debt policy: The case of the US defense industry. *Journal of Financial Economics, 64*, 35–59.
Griliches, Z. (1990). Patent statistics as economic indicators: A survey. *Journal of Economic Literature, 28*(4), 1661–1707.
Guillou, S., Lazaric, N., Longhi, C., & Rochhia, S. (2009). The French defence industry in the knowledge management era: A historical overview and evidence from empirical data. *Research Policy, 38*(1), 170–180.
Halpern, B. H., & Snider, K. F. (2012). Products that kill and corporate social responsibility: The case of US defense firms. *Armed Forces & Society, 38*(4), 604–624.
Hartley, K. (2003). The future of European defence policy: An economic perspective. *Defence and Peace Economics, 14*(2), 107–115.
Hartley, K. (2008). Collaboration and European defence industrial policy. *Defence and Peace Economics, 19*(4), 303–315.
Jaffe, A., Fogarty, M. S., & Banks, B. A. (1998). Evidence from patents and patent citations on the impact of NASA and other federal labs on commercial innovation. *Journal of Industrial Economics, 46*, 183–205.
Jaffe, A., & Trajtenberg, M. (2002). *Patent citations and innovations: A window on the knowledge economy*. Cambridge: MIT Press.
Jaffe, A., Trajtenberg, M., & Fogarty, M. (2000). Knowledge spillovers and patent citations: Evidence from a survey of inventors. *American Economic Review, 90*, 215–218.
James, A. D. (2006). The transatlantic defence R&D gap: Causes, consequences and controversies. *Defence and Peace Economics, 17*(3), 223–238.
James, A. D. (2009). Re-evaluating the role of military research in innovation systems: Introduction to the symposium. *Journal of Technology Transfer, 34*, 449–454.
Kulve, H., & Smit, W. A. (2003). Civilian-military co-operation strategies in developing new technologies. *Research Policy, 32*, 955–970.
Larsen, P. B. (2001). Issues relating to civilian and military dual uses of GNSS. *Space Policy, 17*(2), 111–119.

Lee, J. J., & Yoon, H. (2015). A comparative study of technological learning and organizational capability development in complex product systems: Distinctive paths of three latecomers in the military aircraft industry. *Research Policy, 44*, 1296–1313.
Leten, B., Belderbos, R., & Van Looy, B. (2007). Technological diversification, coherence, and performance of firms. *Journal of Product Innovation Management, 24*(6), 567–579.
Martí-Sempere, C. (2016). What is known about defence research and development spill-overs? *Defence and Peace Economics.* https://doi.org/10.1080/10242694.2016.1239364
Martin, S., White, R., & Hartley, K. (1996). Defence and firm performance in the UK. *Defence and Peace Economics, 7*, 325–337.
Matelly, S., & Lima, M. (2016). The influence of the state on the strategic choices of defence companies: The cases of Germany, France and the UK after the Cold War. *Journal of Innovation Economics & Management, 2*, 61–88.
Mérindol, V., & Versailles, D. W. (2010). Dual use as knowledge-oriented policy: France during the 1990–2000s. *International Journal of Technology Management, 50*(1), 80–98.
Meunier, F. X., & Zyla, C. (2016). Firm growth and knowledge flows: Comparative analysis between defence and civil areas. *Journal of Innovation Economics & Management, 20*, 89–108.
Molas-Gallart, J. (1997). Which way to go? Defence technology and the diversity of dual-use technology transfer. *Research Policy, 26*, 367–385.
Molas-Gallart, J. (2002). Coping with dual-use: A challenge for European research policy. *Journal of Common Market Studies, 40*(1), 155–165.
Mowery, D. C., & Rosenberg, N. (1982). Technical change in the commercial aircraft industry, 1925–1975. In N. Rosenberg (Ed.), *Inside the black box: Technology and economics* (pp. 163–177). Cambridge: Cambridge University Press.
Mowery, D. C., & Simcoe, T. (2002). Is the internet a US invention?—An economic and technological history of computer networking. *Research Policy, 31*(8), 1369–1387.
Mowery, D. C. (2010). Military R&D and innovation. In B. Hall & N. Rosenberg (Eds.), *Handbook of the economics of innovation* (pp. 1220–1256). Amsterdam: Elsevier.
Mowery, D. C. (2012). Defense-related R&D as a model for 'grand challenges' technology policies. *Research Policy, 41*(10), 1703–1715.
Rogers, M. (2004). Networks, firm size, and innovation. *Small Business Economics, 22*(2), 141–153.
Santarelli, E., & Sterlacchini, A. (1990). Innovation, formal vs. informal R&D, and firm size: Some evidence from Italian manufacturing firms. *Small Business Economics, 2*(3), 223–228.
Shefi, Y., & Tishler, A. (2005). The effects of the world defense industry and US military aid to Israel on the Israeli defense industry: A differentiated products model. *Defence and Peace Economics, 16*(6), 427–448.
Stowsky, J. (2004). Secrets to shield or share? New dilemmas for military R&D policy in the digital age. *Research Policy, 33*(2), 257–269.
Trajtenberg, M. (2006). Defense R&D in the anti-terrorist era. *Defence and Peace Economics, 17*(3), 177–199.
Venturini, K., Verbano, C., & Matsumoto, M. (2013). Space technology transfer: Spinoff cases from Japan. *Space Policy, 29*(1), 49–57.
Wallin, M. W. (2012). The bibliometric structure of spin-off literature. *Innovation: Management, Policy & Practice, 14*(2), 162–177.

Wang, T. -P., Shyu, S. H. P., & Chou, H. -C. (2012). The impact of defense expenditure on economic productivity in OECD countries. *Economic Modelling, 29*, 2101–2114.