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Identifying the Intellectual Capital of Greek Defence Firms. Science Outputs and Industrial Considerations

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ABSTRACT
This paper examines the performance of the Greek defence industry in terms of their (co)authoring of scientific publications. In the context of knowledge-intensive technological and industrial policy, science outputs are important indicators of the respective intellectual capital of those firms. This is done through bibliometric analysis. Findings indicate that there is an increase in the number of publications over time. This is attributed to a small number of over performing firms – among which a super performer is identified. In terms of industrial classification, the NACE codes of these over performing firms overlap the respective bibliometric Subject Area Classifications. This is a clear indication of a match between scientific and industrial priorities. On the author level, findings indicate that a small number of authors (one per the top 10 firms) are responsible for a large (and in many cases, disproportionate) percentile of total publications per firm. Fourth, using keyword network analysis, most frequent keywords are detected pointing to specific topological clusters of research hotspots.

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Defence industry; bibliometrics; intellectual capital; publications; science; greece

Introduction – theoretical debate

The paper takes cue from a range of theoretical debates. One strand stands on the extensive utilization of bibliometric analysis to examine the knowledge capacity of the firms as measured through their contribution to the global circulation of knowledge. Bibliometrics can be used for a broad range of problems in research management and research evaluation. Bibliometric analysis can be utilised to delineate research trends or hotspots in various scientific fields (Liao et al. 2018; Rincon-Patino, Ramirez-Gonzalez, and Corrales 2018) or to assess the level of scientific output and impact of researchers (Sugimoto et al. 2017). Since the main objective of our analysis is the exploration of the intellectual capital of defence firms in Greece, through the lens of bibliometrics, certain relevant indicators need to be addressed.

There are a number of reasons that point to the worthiness of examining Greece. While Greece is one of the poorest members of the European Union, yet its defence burden is among the highest in both Europe and NATO (Kollias 1995; Dunne and Nikolaidou 2001). This brings out the question of the extent to a portion of this spending is put into relevant industrial considerations. It is not surprising to note, therefore, that Greece has attracted considerable attention in defense economics literature (Kollias 2004).

A renewed emphasis on domestic industrial transition has also been the case in a post-economic crisis framework (Hellenic Ministry of Development 2019). Herein, defence has attracted attention

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given its sound industrial characteristics as well as the identification of industrial pockets of excellence within the domestic industrial ecosystem – pockets that can be further promoted. Last, the same policy realisations are taking place on the European level. Given the need to re-industrialize, defence industry-specific measures have been introduced with the aim to upgrade their innovation capabilities and internationalise, e.g. a) financial incentives such as the European Defence Fund (Haroche 2018), b) acquisition of innovation-related skills through the European Defence Skills Partnership (European Commission 2019), c) the European Investment Bank's decision to start reviewing investments in European defence R&D under the European Security Initiative – Protect, Secure, Defend and thus start offering attractive financial products in this sector (European Defence Agency 2018), d) another set of incentives involves the inclusion of defence into the national and regional smart specialization strategies (RIS3 strategies): a localised approach to identify strategic areas for intervention based on the analysis of the research and technological strengths and potential of the (local, regional) economy. It has resulted in making the defence firms part of territorial development strategy on the basis of their industrial and technological 'footprint'.[1]

Standing on the bibliography on intangible assets as a firm's source of competitive advantage (Nelson and Winter 1982), scientific publications are considered to be an integral part of the structural (organizational) capital – a sub-theme of the intellectual capital typology – to be appreciated as a form of codified and cumulative asset (Andrews and De Serres 2012; Thum-Thysen al., et al. 2017). More on this, focusing on those non-physical assets that can be a considered to be a source of probable future economic benefits and can be retained and managed by companies (Bontis 1998; Chen, Zhu., and Xie 2004), scientific publications are viewed as a special case of R&D activities that constitute transfering mechanisms to circulate knowledge around among both firms and, especially, through their physical embodiment, i.e. the specific employees-acting-as-authors.

Herein, a problem was encountered. Attempting to identify the standard manner in which the defence-related bibliography views the intangible assets, and more especially publications authored by defence firms, the search results were limited. That is, most studies did not touch the subject at all (Trajtenberg 2006) or focus solely on the management of technological insertion; however without addressing specific science-related aspects such as publications (Kerr, Phaal, and Probert 2008). For those that did, they discussed the matter in a largely peripheral manner stating that defence firms 'are more likely to control their intangible assets' (Matthews 2019), pointing to the classified and limited information realities pertaining defence and, as such, the inability to shed light on the topic. While the card of national security can always be presented with the purpose of putting a stop to such discussion, the fact of the matter is that defence firms by nature of their advanced technological capabilities and high diversification, in terms of human-, structural- and relation-based capitals, in addition to their global character of their operating environment, are long due to adapt to this intangible-based valuation frame of analysis. Given that R&D activities positively affect the market valuation of firms (e.g. Hall, Jaffe, and Trajtenberg 2005), this defence-relevant strand of research can delve into the better-researched realms of pharmaceutical and technology-intensive sectors (Higgins and Rodriguez 2006; Klock and Megna 2000; Mc Namara and Baden-Fuller 2007; Yegros-Yegros and van Leeuwen 2019).

Another important frame to examine the scientific activities of defence firms concerns the importance of knowledge-intensive activities as an enabler of economic growth (Moretti, Steinwender, and Van Reenen 2019; Mowery 2010; Karampekios 2018). Building on the widely accepted findings that human capital and research activities – two essential elements of knowledge-intensive activities – are the leading factors in raising productivity because they facilitate knowledge spillovers and the adaptation of new technologies to economic growth (Carlsson et al. 2009; Harris 2001), defence firms are viewed as a motor towards this. This line of argumentation is based not only on empirical, country-level findings (Yuan et al. 2016), that identify the contribution defence firms on the overall economic growth pattern. It is also squarely placed within the leading theoretical constructs that seek to recognize the elements of the 'knowledge economy' and steer its governance towards increasing levels of optimization, namely the Innovation Systems theoretical approach.

Herein, defence is recognized as a crucial sector (Mowery 2009; Belin and Guille 2019; Lee and Park 2019). It is within this line of tradition and due to the abundance of econometric data and analyses that the hotly debated issue of positive/negative effects defence spending has on the commercial research, innovation and knowledge-intensive activities can be placed. Understanding the knowledge capital of defence firms is, also, placed within the discussion on (reformulating) industrial policies. Again, a means to achieve economic growth through industrial competitiveness that is based on knowledge intensity and the evolving digital innovation and production patterns. In this context, policy makers in advanced economies have realized the significance of the defence sector in terms of turnover, exports, employment as well as an enabler of digitization, automation and sector cross-disciplinarity. In the case of the European Union, this has dripped down to a number of concrete policy measures that seek to boost the defence technological and industrial capabilities, for example by embedding supply chains, integrating defence into regional innovation strategies, fostering new skills and dexterities, in addition to defence R&D and industrial funding (Fiott 2019). Similarly, the US, despite its nominalist rejection of an 'industrial policy', has been practising state-led optimization industrial initiatives for long (Wade 2012, 2017). The point here is that defence industrial policy in the 21st century is firmly placed within a technological intensity rationale, a key aspect of which is the so-called fourth industrial revolution, that seeks to capitalize on science and technology, thus putting a direct link on outputs coming out from these realms.

With an eye to tracing this link and thus encompassing the intellectual capital in the field of defence, this paper stands on a number of existing analyses. For example, Acosta, Coronado, and Marín (2011) examined how civilian economic sectors may take advantage of knowledge embedded in military technology. Also, the exploitation of military knowledge for civilian inventions (spin-off) and the use of civilian knowledge in military-patented technologies (spin-in) is explored (Acosta et al. 2019). Similarly, Schmid (2017), investigated the diffusion of military technologies via patents assigned to defence-servicing organizations. Patents as intellectual property rights constitute the ultimate layer of Europe's defence technological expertise as well as key building blocks to foster defence innovation (Borchert and Helmenstein 2018). On this front, we take cue from another set of studies that utilise patent data (Fujiwara 2017), social media data (Riebe, Schmid, and Reuter 2020) in order to explore job mobility characteristics of knowledge workers or academic research databases to explore the scientific mobility of young scholars (Sachini et al. 2020).

The above debates stand as the theoretical constructs upon which this analysis has been contextualized. For all their strengths and merits, and although scientific publications have been considered as an object of study (Burnett et al. 2018; Fraunhofer 2020), a robust analytical framework taking into consideration the idiosyncrasies of bibliometric analysis has yet to be fully incorporated within the defence-related bibliography. As already indicated, scientific publications embody an important part of both knowledge and capital upon which both industry and the public can capitalise upon. It is within this gap that this piece takes cue from.

Research Question

Following the above, some important questions arise: Is it plausible, by utilising the available sources (scientific databases) and applying Data Science techniques (Data Mining, Data Processing, Data Analysis) to identify and analyse intellectual capital? Can the intellectual capital of Greek defence firms be explored?

Scope and Objective

The scope of this paper is to explore the intellectual capital of the Greek defence firms (hereafter, GDF). By the term 'explore', it should be taken to mean to inquire and provide a range of relevant metrics. These metrics can enhance our understanding of the sector's scientific, technological and industrial performance. Herein the term 'intellectual capital' should be taken to mean the scientific publications in peer-reviewed journals that have been (co)authored by researchers employed by the Greek defence firms, as indexed in Scopus database.

The objective is to use standard bibliometric approaches to inquire about the expressed capability of the Greek defence firms to (co)author scientific papers in acclaimed scientific journals. Using statistical analysis, this capability will be distributed in a manner that highlights the over-performing firms, their industrial classifications. Importantly, those highly capable individuals will also be highlighted. Lastly, by employing keyword co-occurrence, the promising research hotspots will be pointed out.

Contribution

Given that defence is a high-tech industrial class, the issue of identifying the science output formulating and composing this sector has come to the fore. This has been the case also in other industrial fields that are science and tech-enabled, e.g. pharmaceutical industry, see Yegros-Yegros and van Leeuwen (2019). Thus, examining the bibliometric performance of such a sector stands as a legitimate avenue with the aim of identifying the scientific foundation of this industrial class.

Bibliometrics can be used for a broad range of problems in research management and research evaluation. Within the context of bibliometric analysis, specific metrics pertaining to the number of publications produced by a research unit or group, and, in our case, firms (scientific output), the number of authors of each publication (scientific collaboration) (Waltman and Noyons 2019), and the keyword co-occurrence network (delineation of research trends and hotspots within various scientific fields) (Liao et al. 2018; Rincon-Patino, Ramirez-Gonzalez, and Corrales 2018) were utilised.

Within the field of defence, bibliometric analysis has already been used. Such cases aimed at identifying key areas of R & D either within the framework of advanced materials and manufacturing (Burnett et al. 2018) or within the premises of technological foresight for planning and consulting (Fraunhofer 2020). Building on these, this paper identifies science outputs of national defence industries with the aim of exploring the intellectual capital of those firms, a parameter that is highly helpful for incentivizing strategic defence industrial planning.

Given that defence is a scientific and technology-intensive sector, understanding the science outputs of defence firms highlights the scientific foundations of this sector as well as fits squarely within the wider debate on knowledge incentives for economic and industrial growth. Realisation of these, brings to the fore the potential for similar national studies to explore the knowledge capital of the domestic defence sector and to connect the sector with wider developmental and economic considerations (Castellacci, Fevolden, and Blom 2014a; Castellacci, Fevolden, and Lundmark 2014b). Bibliometrics is a field of study that has already been put to use in specific industrial areas, i.e., to stress the importance of Open Access publications in pharmaceutical industries (Yegros-Yegros and van Leeuwen 2019), discover research focuses on service innovation (Zhu and Guan 2013), in more generic concepts such as innovation policy (Lee and Su 2010) and information technology management (Choi and Hwang 2014; Khan and Wood 2015). In addition to contributing to the wider academic debate, the above brings a strong policy interest. This is the case since large funding mechanisms (e.g. RIS3, industrial transformation, digitalisation, digital skills) have been developed on the national and European levels with the aim of upscaling the knowledge-level and technological capacity of defence.

Data and Methods

As a first step, it was necessary to establish which were the domestic defence firms. To do so, we cast a large conceptual net. Specifically, three data sources were employed. The one concerns the Registry of Manufacturers of Defence Material. This registry is preserved, updated and regulated by the Greek Ministry of Defence and concerns those firms that have been accredited by the Ministry as capable of delivering defence and defence-related public work. The two other registries are sectoral. That is, in Greece, two defence industrial associations have been registered. The one is the Association of Greek Defence Material Association (SEKPY) and the other is the Hellenic Association of Space Industry (H-ASI). SEKPY has a clear-cut defence industrial orientation, whereas H-ASI focuses on space, including its defence and defence-related applications, technologies and products. Members of both were harvested. Given that we collected those firms that have been accredited as defence-relevant by the domestic public authority (Ministry of Defence) as well as that are members of the dedicated industrial associations, the following table (Table 1) presents the number of those firms. After removing duplicates (firms existing in more than one category) the total number of firms that we focused on amounts to 169.

To employ bibliometric analysis on the outputs of those firms, it was required to obtain the English name of the firm. Of the 169 industries, 137 industries (81%) had their names provided in the registries with Latin characters, including their English commercial name. Mostly in the case of the SEKPY registry, a number of firms were provided only under their Greek commercial name. These firms were transliterated into English, following (Karakos 2003; Chalamandaris et al. 2006). The number of those firms amounted to 32 (19%). To cross-check the reliability of the aforementioned transliteration process, and as such, confirming the existence of those firms, it was decided to make use of standard search engines (Google). Specifically, relevant queries having as input the transliterated firm names were performed. Where applicable, through optimization, the transliteration of all 32 firms was finalized.

In order to explore the intellectual capital of those Greek defence firms, the relevant knowledge/scientific assets needed to be explored. As said, a specific asset in question is scientific publications. To examine the relative performance of those firms, we employed data science techniques in order to examine the presence of these firms into the standard bibliometric databases. Bibliometrics is a growing field of informetrics that includes the production, dissemination, and use of all forms of information, regarding published research studies (Sutherland 2000). For the purposes of this research, two main bibliometric databases were complementary utilised: Scopus and Web of Science (WoS). Scopus is a source-neutral abstract and citation database, curated by independent subject-matter experts indexing 75+ million records places and 5.000+ publishers. Similarly, Web of Science's platform enables publication analysis across disciplines and time from over 1.7 billion cited references from over 159 million records. Web of Science and Scopus are the two most extensive databases (Chadegani et al. 2013) that provide sufficient stability of coverage (Harzing and Alakangas 2016). Thus, one can safely assert that these two bibliometric databases are the dominant global players in the field providing a near-total coverage.

However, due to the intrinsic sensitivity of information relevant to the defence sector (Heidenkamp, Louth, and Taylor 2015), the authors of this paper are not unaware of the possibility that codified knowledge in the form of relevant publications may not be (publicly) accessible. This has been already been discussed in a number of publications relating to the existence of secrecy in

Table 1. Distribution of the domestic defence firms across registries.

	Number	Total (excluding those overlapping
Registry of Manufacturers of Defense Material	32	33
SEKPY	129	
H-ASI	41	
Total	202	169

Note on Table 1: registries and names of firms were downloaded in February 2020.

Table 2. Distribution of the total number of authors and publications with reference to all firms throughout the interval 1987–2020.

Firms	Publications	Authors	Subject Areas
41	652	286	23

defence industries (Shuldiner 1999), the examination of the role and subject orientation of certain classified communities (Westwick 2000) as well as biotechnology involvement in weapons of mass destruction (WMD) and global terrorism (Rappert and Balmer 2007; Shostak 2008; Lewis Keith 2002).

In any case, although one cannot corroborate the non-existence of certain classified publications, this study proceeded in its aims within the scope of the publicly available databases.

Data Scraping

As a first step, identification of each firm within the Scopus database was pursued. Importantly, it was assumed that firms being rational agents seeking to maximize their value would seek to position their commercial name next to the actual author of the publication in the affiliation section of the paper. That is, the specific publication would contain not only the name of the actual employee that authored the specific publication but also the commercial name of the firm under the auspices of which the specific employee authored the piece.

As such, using each firm's commercial name as a keyword variable, Scopus database was searched. Specifically, since each affiliation indexed in Scopus is associated with an ID (Identification Data), the built-in field named as 'Affiliation' was used and parsed. Importantly, this Scopus feature is dedicated towards identifying authors based on their affiliation. This was achieved by an algorithm implemented within the Python (3.7.3) environment. This approach turned out that only seven Greek defence firms had a Scopus affiliation ID registered. Given that it was only seven out of 169, additional research was carried out. Given that the 'Affiliation ID'-based approach did not provide sufficient results, the Scopus section 'advanced search' was probed. Modifying the same algorithm, queries with the following structure were performed in this feature:

<u>Queries Structure in Scopus</u>

AFFIL('FIRM NAME') AND AFFILCOUNTRY('GREECE')

Through this iteration, 34 additional firms were identified as entities that had had scientific publications registered under their commercial name. Thus, the total number of firms detected within Scopus database amounted to 41.

To verify the outcomes of the research, the Web of Science (WoS) database was also probed. All 169 firms were searched for. Of the Scopus-found firms (N = 41), only 29 were identified in WoS. Of those, in 21 cases, the number of publications was identical to those identified in Scopus and in the case of 8, less. In the latter case, a 'wide net' approach was employed and as such, the larger set of publications, already identified in Scopus, were taken into consideration. None of the remaining 128 firms (i.e. N = 169–41) was identified as having a registered publication under their commercial name. Each firm name was parsed inside WoS, searching via (a) the built-in 'Address' variable as well as (b) performing ''advanced search". The queries used the following structure:

<u>Queries Structure in Web of Science</u>

AD = ('FIRM NAME') AND CU = ('GREECE')

No further results were provided.

Data Collection

The identification of the aforementioned 41 firms enabled the research and allowed the locating and downloading of information relevant to their bibliographic profile. Specifically, the following variables related to the bibliometric performance (Waltman and Noyons 2019) of each firm were the subject of the retrieval process: number of authors, number of authors' publications, year of firms' publications, the subject areas, as well as the corresponding author keywords of each publication. Regarding the scientific publications' subject areas, they were also retrieved as indexed in the Scopus database. Importantly, the existing Scopus' classification for categorising specific subject areas was utilised.[2]

This information was deemed as relevant for the research study. An algorithm (via forming XPath queries) using as input each firm's name and output the aforementioned bibliometric variables was implemented within the Python (3.8.1) environment.

Two nested dictionaries were created. The main one used the firm names as 'keys'. The second used the publication year, the authors' names, the authors' publications, the subject areas and the keywords as 'keys'. An example of the structure of the final firm profile follows:

{'Firm name': {Year: ('Authors' Name', 'Number of Publications'), Subject Areas: ('Field', 'Number of Publications'), Keywords: [keywords per publication]}}

e.g. Firm '12345' has in total 10 publications (4 by author XX in 2018 and 6 by author YY in 2019). Of the 10 publications, 8 fall in the scientific domain of Engineering and 2 of the Social Sciences.

{'12345': {2018: (XX, 4), 2019: (YY, 6), Subject Areas: (Engineering,8), (Social Sciences,2), Keywords: [keywords per publication]}}

The dataset regarded the time interval from January 1987 to April 2020 and the download took place on 04/07/2020.[3]

Data Analysis

The bibliometric data were analysed in order to perform a descriptive analysis of the scientific community (authors) and outputs (publications). This was conducted in combination with the identified firms.

More specifically, on a macro-level, for each firm, the scientific productivity in terms of the number of scientific publications per year was measured. This was conducted in order to identify the top performing firms (in terms of number of affiliated publications). On a micro-level, the researchers that compose the firms' intellectual capital were identified. The latter was conducted with the aim of identifying the top performing author for each firm. In that way, the level of the author's contribution to a firm's scientific output was assessed. We follow the standardized classification frame 'NACE Rev. 2 – Statistical classification of economic activities', [4] as a means to obtain a perspective of each firm's subject orientation, the industrial classification of the most productive firms was collected. Additionally, the underlying subject areas across all publications were harvested. This would provide an overview of all the contributing scientific areas in relevance with the subject orientation of the industries. Also, with reference to the identification of emerging topics, a keyword network analysis was performed. The analysis focused on the 'keyword' part of the documents, where authors insert the most specific, representable and findable concepts that they deem their paper is associated with. In terms of emerging topics, presenting a network depicting the most frequent, interconnected keywords, one can acknowledge the scientific trends with which the authors aspire their papers to be associated with.

With regards to descriptive analysis, as an initial step, the total number of authors as well as the total publications were calculated. For each publication year – that is, the year that each specific scientific publication was recorded by Scopus – a plot depicting the scientific activity of all firms was created. Moreover, the average percentage of the relevant (specific and generic) subject areas attributed to each publication were computed. In an attempt to highlight firms and authors who stand out in terms of productivity, relevant graphs are presented regarding the top 10 firms together with the representation of their industrial classification.

As regards the keyword network analysis, in order to schematically point out the emerging topics (knowledge flows) derived from the scientific publications a network graph was constructed. This was achieved by performing keyword analysis. Keyword mapping constitutes an essential element in bibliometric analysis (Kouropalatis, Morgan, and Karhu 2016). Viewed in combination with a scientific framework, it can imprint the discipline situation and the development status within (Garousi and Mäntylä 2016; Liao et al. 2018). There are many software for performing such bibliometric analysis. In this paper, VOSviewer (Centre for Science and Technology Studies, Leiden University, Leiden, The Netherlands) was used.

Results

The results section is divided among four sub-sections. Part 1 presents the number of publications, the distribution over time and the subject areas under which these publications can be classified. Part 2 employs a firm-oriented view. The most and least productive companies are identified and this is tied to their respective fields of industrial activities. Part 3 focuses on the authors. That is, these authors that have been most prolific in the authoring of these publications (overperformers) are identified. Part 4 explores a specific variable found in the publications. Their annotated keywords. Through keyword co-occurrence, major science hotspots are highlighted. In addition, we proceed to a co-occurrence graph to visualize the above.

Part 1: The Current Status of GDF's Science Outputs Performance

The total number of publications with reference to all the firms (41) identified in the Scopus database amounts to 652 (Table 2). The corresponding authors of those firms amount to 286. Following Scopus' categorization (see section *'Data Collection'*), these publications pertain to 23 different subject areas.

Figure 1 plots the annual trends of GDF's science outputs. According to the documentation provided, the first article was published in 1987. Since then, a relatively slow increase in the following 17 years until 2004 can be observed. After this period and between 2005 and 2008, scientific publications reached their (local) maximum (45 documents in 2007) until gradually decreasing for the next 5 years (23 documents in 2013). From 2014 and on, the number of publications increased substantially, reaching its (global) maximum in 2016 (54 publications). Two points are worth considering here. The first one concerns this increase after 2014. Potentially, this can be attributed to the introduction of defence as a European R&D funding priority (Karampekios, Oikonomou, and Carayannis 2017; Karampekios 2018). Among the list of expected deliverables, scientific publications are a preferred outcome of a European-level R&D collaborative arrangement. Analysis of the 'disclaimer' and 'funding acknowledgement' parts' of each publication in future bibliometric analyses can explore this. The second point refers to the steep decrease observed in 2020. This is to be attributed to the fact that the bibliometric dataset downloaded had not (at the time of the download) incorporated the 2020 publications. There is a time-gap between the publication time and the

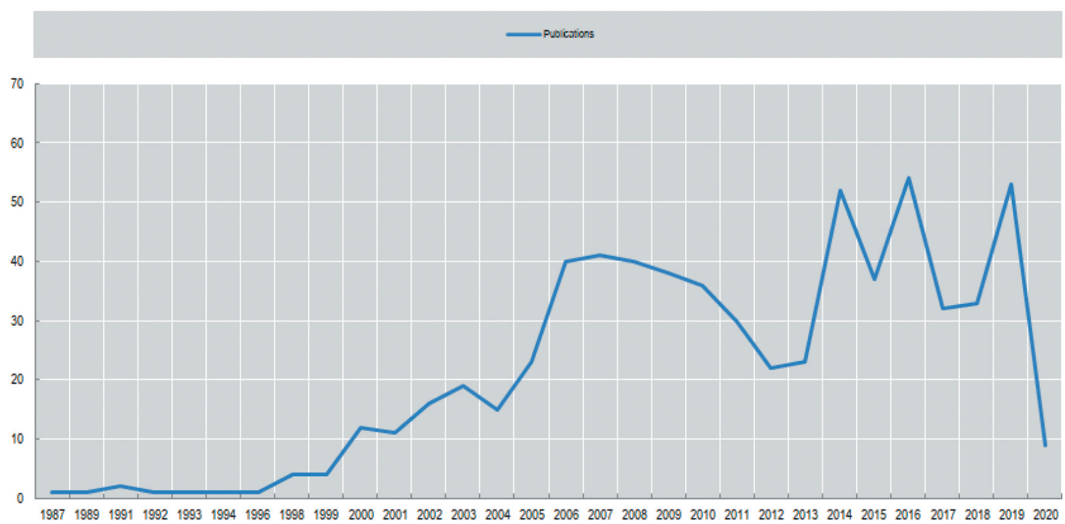

Figure 1. The annual trends of GDF's science outputs. Years: 1987–2020.

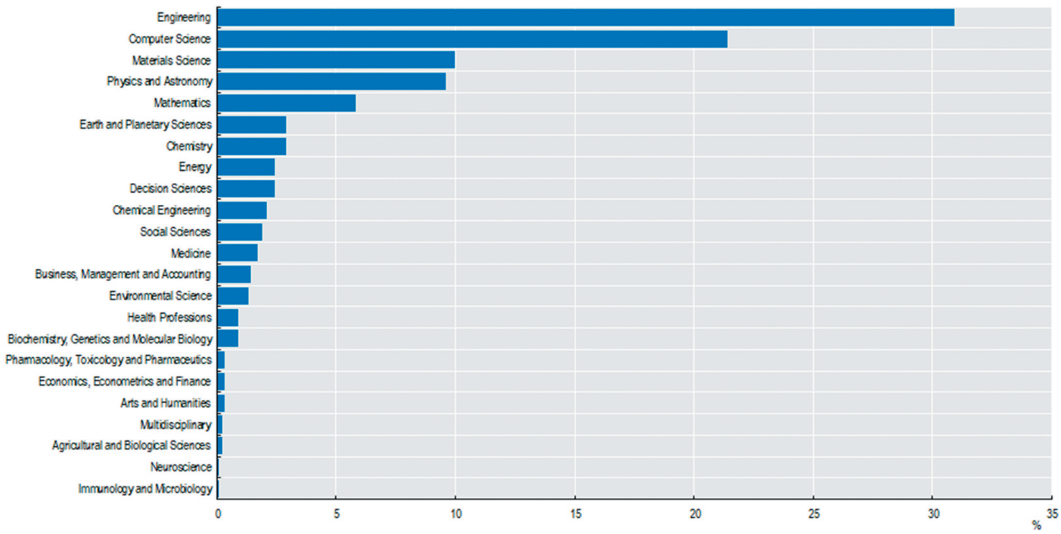

Figure 2. The specific Subject Areas Classifications of GDF-related publications (%).

time this is bibliometrically measured. This is a systemic observation found in all bibliometric analysis. In all probability, the 2020 yield would be higher.

Figure 2 presents the distribution of the subject areas of these publications. For all 652 publications, a specific scientific Subject Area Classification according to the Scopus taxonomy was attached. 'Engineering' constitutes the scientific subject area under which the greatest number of publications have been categorized with a total of 202 papers, accounting for 31% of all publications overall fields. 'Computer Science' (143 papers – 22%), 'Materials Science' (65 papers – 10%), 'Physics and Astronomy' (63 papers – 9.6%) also make an important contribution to the GDF's knowledge capital. The super-set of the Subject Area Classification class is the Subject Area Class. The publications are, thus, classified accordingly in **Figure 3**. 580 papers (89%) fall under 'Physical Sciences'. This is the most contributing scientific subject area. 'Social Sciences' (39 papers – 6%), 'Health Sciences'

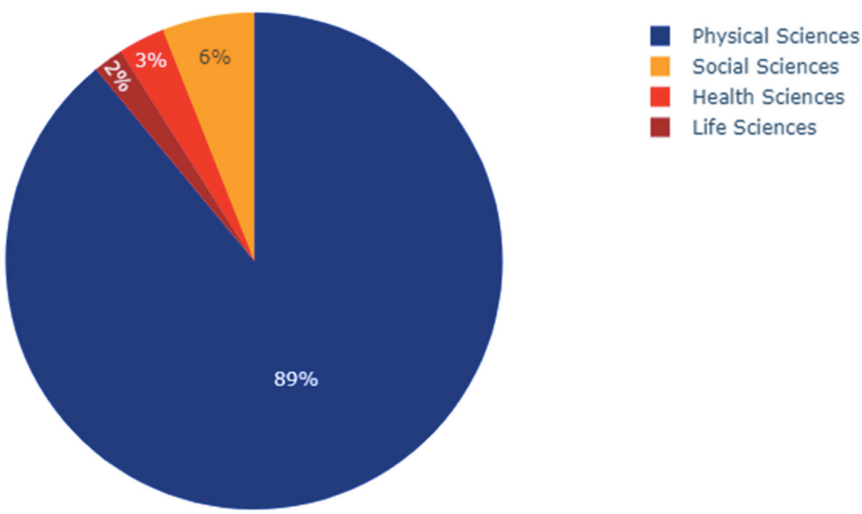

Figure 3. The generic Subject Areas of GDF-related publications.

(20 papers – 3%) and 'Life Sciences' (13 papers – 2%) complete the scientific map of the GDF's related publications.

Part 2: Focusing on the Firms

In **Figure 4**, the most and least productive firms in terms of number of publications are presented. Firms are positioned on the x-axis in relation to their number of publications; the order is descending. Firm #1 clearly outperforms the rest of the firms with 114 affiliated publications. Firms (#2 to #8) have corresponding affiliations in more than 30 scientific publications each. From Firm #15 downwards (until Firm #41), no firm has more than 15 publications in total. One can point to a national system that comprises an outstanding firm in terms of science outputs and a small number of followers that manage to sustain a science production.

In the following figure (**Figure 5**), the top 10 firms are distributed in relation to their first bibliographic appearance as well as presented over the entire examined time period. Firm #1 appears to have been a long-standing contributor in the form of science output (super performer) – being active since 1987. The majority of the remaining firms have become bibliographically active around the 2000s – meaning that they have been amassing this type of intellectual capital for approximately 20 years – not a small period of time. Only a few have become active during the last decade or so. Interestingly, though, firm #3 despite being one of the most recent bibliographic entrants – having an affiliated publication only in 2009 -, has managed to number 55 publications according to **Figure 5**. Indeed, in 2014 scored 13 publications – a max. among all top-10 firms.

The issue of industrial classification of those firms is important. Identifying the specific industrial class under which these firms operate would signal in a direct manner those classes that are highly productive in terms of tangible science outputs, i.e. scientific publications. To do so, the standard 4-digit NACE codes were made use of.

Figure 6 provides an image of the industrial classification of the top 10 firms. Firm #1 is classified as Manufacture of air and spacecraft and related machinery ('3030'), whereas firms #2 and #3 and #8 as Computer programming activities ('6201'). This indicates that such firms have identical subject orientation, in particular Computer Science oriented subjects.

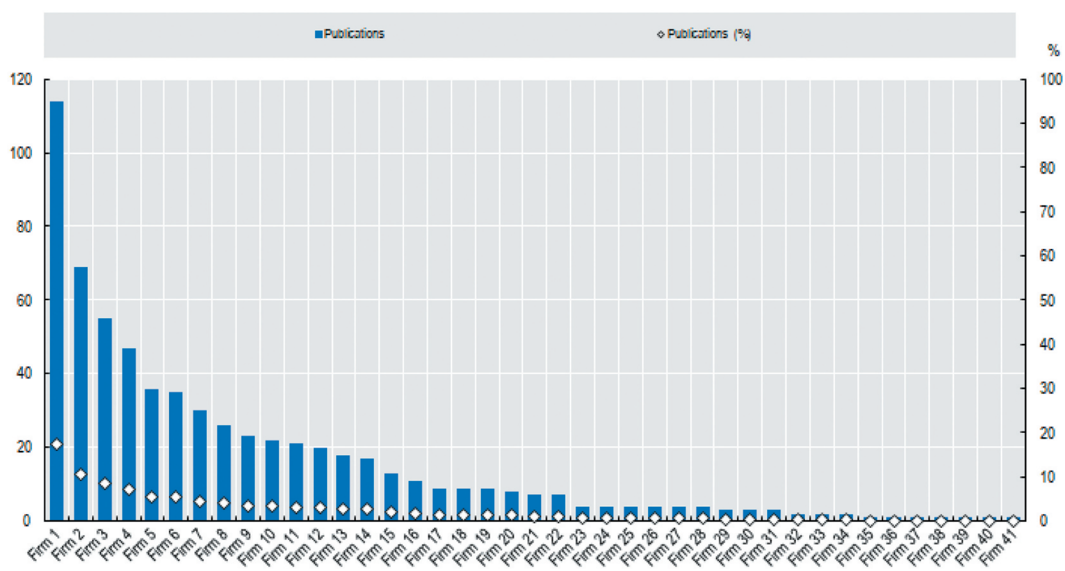

Figure 4. Distribution of firms according to their number of publications, period: 1987–2020.

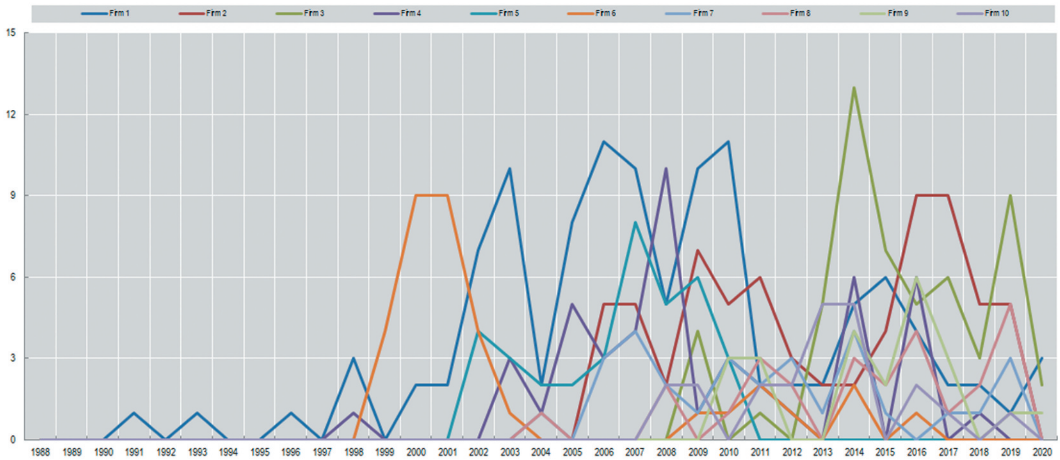

Figure 5. Annual publication trends of the top 10 performing firms, period: 1987–2020.

In all, the industrial classification of the top 10 appears to match with most contributing ('Engineering', 'Computer Science', 'Materials Science') 'specific Subject Areas Classifications' of their respective publications, as presented in **Figure 2**. This is an important finding indicating that the scientific classifications are in line with the industrial ones.

Part 3: Focus on the Authors

Scientific publications are not authored by firms. They are authored by individuals who are highly trained in terms of educational degrees and operational experience. These authors are employed by the firms as contractors, employees, etc. As such, it is of importance to remember that while scientific articles should be considered as firm's intellectual capital, a more precise definition would characterize scientific papers as the embodiment and the written formalization of an employee's research capability within a specific industrial setting that makes use of the firm's industrial and technological assets.

In the following figure (**Figure 7**), the authors of the top 10 performing firms are examined (see **Figure 4**). Specifically, the number and the distribution of each firm's top author in terms of number of his/hers (co)authored publications with respect to the firm's total number of publications is presented. In addition, the number of publications (co)authored by other authors within the same firm are also presented. Importantly, in the latter case, those publications do not contain the top author – that is, the latter group of publications were (co)authored by firm employees other than the top author. Comparison between the first author and other authors would indicate the redundancy capacity of the firm in the sense that understanding the depth in terms of capable human capital in undertaking the (co)authoring of an academic publication.

For example, in the case of the first (#1) firm, the most productive author ('top author') has (co) authored 26 scientific papers out of the 114 in which his/her firm is affiliated with. Other authors by the same firm have been involved with the (co)authoring of the remaining 88. That is, the top author has been identified as part of the authoring group in 22.8% of the total cases. Significantly, in the first four firms, the percentile attributed to the top author is within the range of 20% and in no case above 23.4% – that is a quarter of all paper. In the remaining six firms, the pattern changes. These highly productive individuals are much more represented in the totality of the firm's scientific papers. With the exception of one firm (#8), the percentile attributed to those individuals is at least half of the total, and in three cases they are identified as literally almost always part of the authoring group. Thus, one can speak of overperforming individuals, a trait all the more evident in those firms with

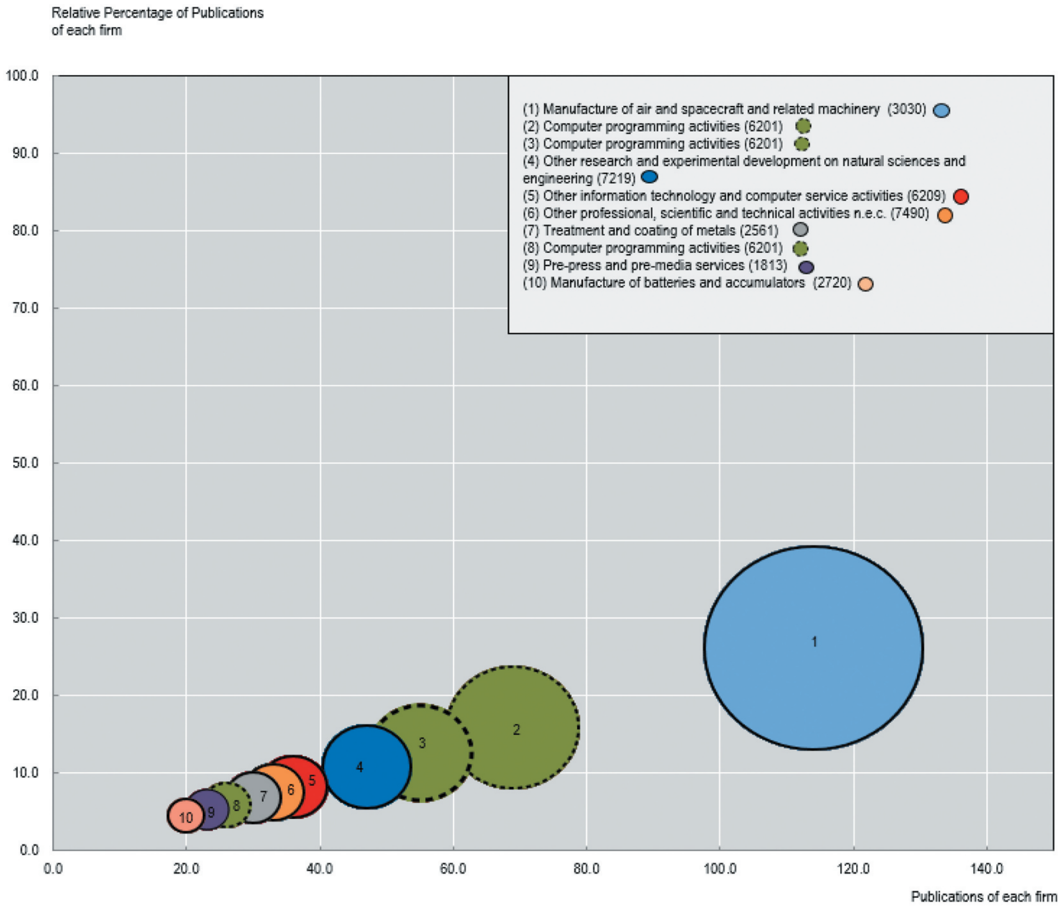

Figure 6. Representation of the industrial classification of the top 10 firms. Note on Figure 6: following the NACE Rev.2 – Statistical classification of economic activities, see https://ec.europa.eu/eurostat/web/products-manuals-and-guidelines/-/KS-RA-07-015

fewer number of publications where the lead authors take a disproportionate % of total. Pointing a finger at the embodiment of the intellectual capital of the firm, with increased assurance, one could point to those individuals as the sole responsible for (co)authoring those papers. In the case of the first four firms, a much greater redundancy capability is observed.

Part 4: The Keyword Network Analysis of Scientific Publications on GDF Study

Keywords co-occurrence can help point out research hotspots in diverse discipline fields, thus providing auxiliary support for scientific research (Van Eck and Waltman 2014). Authors themselves choose the specific words in their strive to achieve representation of their work and link to existing debates. As such, they can be considered as classification proxies for technological and industrial priorities, especially if seen across time.

In all the 652-related publications, 6.698 keywords were obtained. Among them, 4.482 keywords appeared only once, accounting for 67%.

The keyword co-occurrence network (see **Figure 8**) was constructed using the VOSviewer (VOS) software. It contains condensed and distributed information about the underlying subject areas, science topics and research hotspots.

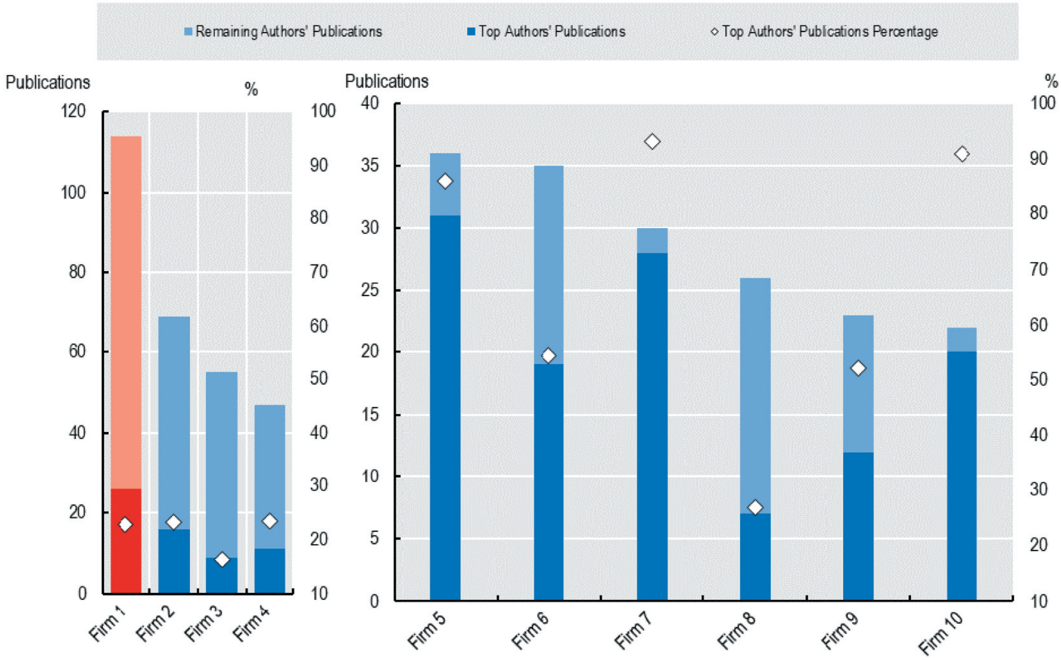

Figure 7. Distribution of each firm's top (most productive) author publications with respect to the total number of publications in each firm. The top 10 most productive firms were considered.

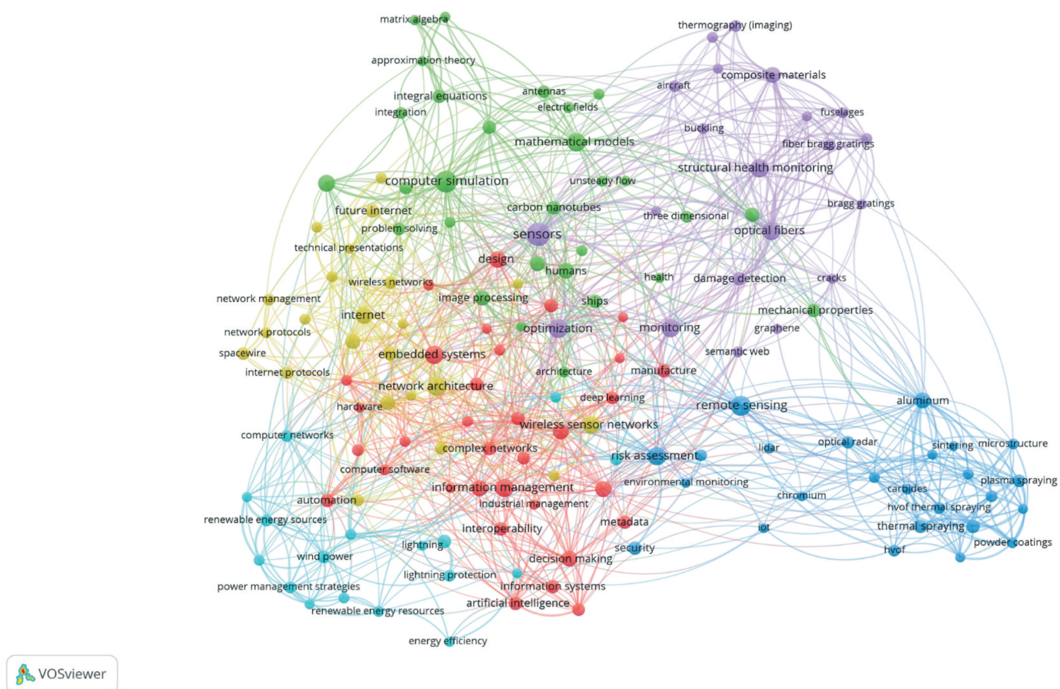

Figure 8. Keywords co-occurrence network of GDF-related publications.

The size of the nodes and words represents the weights (impact) of the nodes. The larger the node and the word are, the larger the weight is. The distance between two nodes reflects the strength of the relation between two nodes. A shorter distance generally reveals a stronger relation. The edge (line) between two keywords represents that such words have appeared together. The thicker the line is, the greater their co-occurrence (Liao et al. 2018; Van Eck and Waltman 2014). Nodes with the same color belong to the same cluster.

Selecting as a similarity measure the *association strength* and using the default parameters regarding the layout and clustering, VOS divided the keywords of GDF-related publications into six clusters. The graph was constructed taking into account keywords with at least seven occurrences and as a result only 148 keywords met the threshConcerning the keywords' frequency, the keyword 'sensors' has the highest frequency of 35. The term was used as a keyword in 35 articles. Other keywords with a high frequency include 'computer simulation' (30), 'remote sensing' (26), 'network architecture' (24) and ''optimization'' (23). Confirming the results of **Figure 2**, such terms constitute terms within the sphere of the most contributing Subject Area Classifications: 'Engineering', 'Computer Science' and 'Materials Science'.

The link strength between two nodes refers to the frequency of co-occurrence. It can be used as a quantitative index to depict the relationship between two nodes (Pinto, Pulgarín, and Escalona 2014). The total link strength of a node is the sum of link strengths of this node over all the other connected nodes. The node 'sensors' (pink cluster) connects directly with at least one keyword of all other clusters ('computer simulation' – green, 'internet' – yellow, 'renewable energy sources' – light blue, 'artificial intelligence' – red and 'aluminium' – blue cluster). Overall, the node is linked with 61 other nodes and especially with 'monitoring' (11), 'optical fibers' (10), 'structural health monitoring' (5) and 'optimization' (4). The relationships between 'sensors' and 'monitoring' as well as 'optical fiber' and 'optimization', in the context of defence, indicate their integration under the technological domain of smart monitoring systems.

The following two nodes with the highest frequency (**Table 3**), ''computer simulation'' and ''remote sensing'', are interconnected via the nodes ''mathematical models'' (4) and ''image processing'' (5) which in turn is connected with ''deep learning'' (4) and this with 'artificial intelligence' (2), then ''information management'' (3), 'industrial management' (2) ending up at the node ''decision making'' (4). This path reveals the technological, scientific and methodological components involved in decision-making, highlighting the importance of data science methods in (defence) policy (Omar and Kleiner 1997; Guay 1998). In addition, the nodes 'decision-making', 'metadata' and 'security' have a relatively small distance. This indicates that although clustered in different groups, these keywords are strongly related.

Evidently, throughout the network, diverse knowledge flows support the same, interrelated topics. The tracing of such flows adjusted to the need, subject orientation or research interest reveals the underlying scientific trends. Such perspectives consider scientific publications as links in an interconnected network of knowledge. The interconnectedness' attribute is key to acknowledge the

Table 3. The top 10 keywords of the GDF-related publications.

Rank	Keywords	Frequency	Links	Total Link Strength
1	Sensors	35	61	129
2	Computer simulation	30	42	65
3	Remote sensing	26	44	76
4	Network architecture	24	41	51
5	Optimization	23	51	85
6	Embedded systems	22	43	67
7	Optical fibers	21	44	96
8	Structural health monitoring	21	38	101
9	Mathematical models	21	36	60
10	Information management	21	31	56

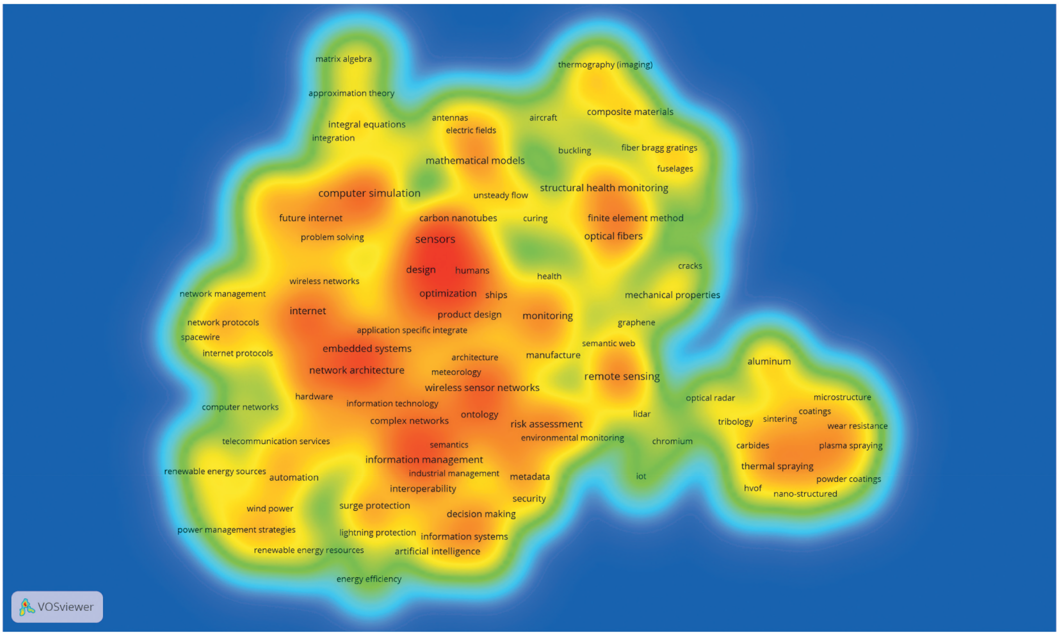

Figure 9. Keywords density visualization map of GDF-related publications.

importance of scientific publications as intangible assets for any industry-specific analysis (e.g industry-specific factors related to decision-making processes).

Additionally, density visualization is presented with the aim of depicting the core keywords – focal points. Each node color in the keywords density visualization plat relies on the density of items at that node. In other words, the color of a node depends on the number of items in the neighborhood of the node. The keywords in the red or orange color area are those that appear more frequently; on the contrary, the keywords in yellow or green color area appear less frequently.

Density views are especially useful for understanding the overall structure of a map and drawing attention to the most important areas in the map (Chawla and Davis 2013). Specifically, **Figure 9** highlights specific clusters of keywords, e.g. 'sensors', 'design', 'optimization', 'network architecture', 'embedded systems', 'information management' and 'industrial management'. These clusters indicate the wider, interrelated, technological and industrial fields, such as smart monitoring systems and network monitoring. Such keywords are central to the specific GDF architectural topology.

Discussion

To our understanding, bibliometric analysis concerning defence industries is a little touched field (Burnett et al. 2018; Fraunhofer 2020). As such, the issue of addressing the intellectual capital of those firms as well as the sector as a whole can certainly attract more attention. All the more so, given the knowledge-intensity of the sector. This paper is one of the few to do so. While the paper refrains from offering company-centered valuation approximations of these science outputs, shedding light on the bibliometric methods to explore these outputs contributes towards a variety of analyses. Such analyses can be extended to similar national and/or supranational contexts.

Focusing on the Greek defence industrial sector, within the scope of this paper, it was attempted to identify a range of relevant bibliometric indicators and the sector's performance. Cross-temporal analysis indicates that the number of publications produced by GDF increases. Since 2014, domestic industry manages to score substantially higher numbers of science outputs (in comparison to the prior period), a trend that can be potentially attributed to the European-level defence R&D funding. Of the top 10 GDF firms, most have been recorded as having started to contribute to the global circulation of knowledge by way of publications during the 2000s. Exception stands firm #1 which has a much older bibliographic long-standing (super performer).

Additionally, the Subject Area Classifications of these publications indicated that most fall under 'Engineering' as a classification group. This is followed by 'Computer science' and 'Materials Science'. This is an expected finding given the strong engineering background and applied approach of this industrial sector. In all likelihood, the same evidence should be observed in similar national analyses.

In terms of specific firms, those most capable of publishing their results were identified. Also, the sectoral orientation of these firms was pointed out. Making use of NACE codes, it was possible to identify the fields the firms themselves mostly associate with, thus bringing out a much clearer view of the 'true' industrial priorities. Results indicate that there exists one firm that outperforms all others (in terms of number of scientific publications) and is classified in terms of economic activities as 'Manufacture of air and spacecraft and related machinery' (NACE Rev2 code – 3030). This firm is the Hellenic Aerospace Industry (see Appendix). The Hellenic Aerospace Industry is one of the largest industrial enterprises in Greece (Loukis, Spinellis, and Katsigiannis 2011). Since 1975 it has been one of the major state-owned defence companies in Greece with 3,000 employees and an established reputation in the international market as a reliable service provider and business partner in the field of combat and civilian aircrafts (Inkster 2017). For this as well as other firms, their industrial classifications appear to verify the specific Subject Areas Classifications of their respective publications. This indicates that the scientific classifications are in line with the industrial ones.

On the author level, a few select individuals have been identified as having consistently (co) authored a substantial portion of the firm's publication output. In some cases, those high performing individuals account for the great majority of that output to the extent that it can be argued that they embody the intellectual capital of the firm.

The resulting clusters of the keyword co-occurrence analysis reflect the industry-specific knowledge flow derived from the GDF-related scientific publications. Such components of the constructed 'knowledge-flow' map constitute a valuable imprint of the intellectual capital of the GDF. Moreover, they can be related to elements highly topical with defence industrial policy as well as national security. Within the premises of both these considerations, findings indicate that exploitation of cutting-edge technologies is crucial.

This is especially so given that the sector is technology- and knowledge intensive. This realisation has prompted relevant policy considerations by, e.g., the European Commission to enhance the sector's technological and industrial capabilities. This is sought by increasing the R&D performance, integrating defence into regional innovation strategies (RIS3), fostering new skills and dexterities of the both the employees and firms classified as defence. The same holds in the US. It is in this industrially related context that a critical aspect of the tangible knowledge both produced and 'consumed' by these firms, i.e. scientific publications, is an untapped intellectual capital. Indeed, what has been shown here is that a small number of firms are 'national champions' in terms of science outputs – a key input in the formation of a robust, technology- and knowledge intensive, industrial policy for defence in the 21st century.

On a parallel footing, what is interesting concerning the literature on intangible assets being viewed as a source of probable future economic growth, is the difficulty of establishing a standardized, consistent and validated enough method to evaluate their contribution for every industry at large (Stewart 2010; Bontis 1998). An aspect of this ambiguity potentially lies in the strain of putting a dollar mark-up in scientific outputs such as scientific publications.[5] This paper, while addressing a sector- and country-specific theme, has, hesitantly, touched upon this difficult subject. Indeed, one can argue that regularly monitoring the publication performance of firms through extensive bibliometric analysis, focusing on impact and citation analysis, can yield results contributing to the much sought-after intangible-assets monitoring mechanism that valuation and consultancy companies strive for.

Next Steps

As already stated, this was a first attempt to address the intellectual capital of the defence sector. Obviously, other country-level analysis can pave future research avenues. In terms of bibliometric analysis, the examination of the impact of these papers can shed more light on the value of these papers. In matters of authorship, it would be interesting to examine whether the authors-employees of academic papers do have a second, parallel affiliation, e.g. with a university or a public research centre. This would show in a very pragmatic, bottom-up, manner the actual relation between industry and academia – a long-sought goal – as embodied by those very capable individuals. The assumption that the increase in the number of publications can be attributed to the insertion of defence as a standard R&D funding priority within the scope of European competitive projects, can be explored by way of analyzing the 'disclaimer' and 'funding acknowledgement' parts' of each publication in future bibliometric analysis, thus highlighting the European funding as the relevant enabler.

Additional to standard bibliometric databases, such as Scopus and Web of Science, data from alternative metrics (e.g. on social media) as well as from conference proceedings, is a future option.

Technological outputs, such as patents, trademarks, etc., as well as the setting of start-ups affiliated with the mother-companies, would allow researchers to understand the commercialisation process of these science outputs.

Correlation of bibliometric performance with other R&D-relevant indicators, such as spending and highly educated personnel as a fraction of total employed, as well as comparison with other science and technology-intensive sectors, such as pharmaceuticals, is also an avenue for future exploration.

Notes

1. See the dedicated website of the European network of defence-related regions: https://www.endr.eu/
2. We follow the Scopus All Science Journal Classification (ASJC) model. See: https://service.elsevier.com/app/answers/detail/a_id/14882/supporthub/scopus/~/what-are-the-most-frequent-subject-area-categories-and-classifications-used-in/(accessed: 22/4/2020).
3. Available here: http://www.ekt.gr/sites/ekt-site/files/GDF_Firms_and_Authors.xls
4. **https**://ec.europa.eu/eurostat/web/products-manuals-and-guidelines/-/KS-RA-07-015
5. This ambiguity is far from settled. For an update, see reference #9 in Thum-Thysen et al. 2017.

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