FEDERAL UNIVERSITY OF MINAS GERAIS

RODRIGO FILETO CUERCI MACIEL

TECHNICAL RESEARCH INNOVATIONS OF THE US NATIONAL SECURITY SYSTEM

Technological portfolio and impact evaluation

BELO HORIZONTE

2019

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RODRIGO FILETO CUERCI MACIEL

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Belo Horizonte, 26 de agosto de 2019.

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A Comissão considerou a tese:

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Belo Horizonte, 26 de agosto de 2019.

Prof(a). Marta Macedo Kerr Pinheiro

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ABSTRACT

Since the Second World War the US defense has been a major participant in the development of radical innovations in information and communication technologies, most famously probably the digital computer and the internet. A regularly present, but less known creator of R&D innovations is the intelligence community. To understand the role and impact of defense and intelligence-related research for driving innovations, using bibliographic analysis, we analyzed the scientific output promoted by the US National Security System and its impact on selected fields. Thus, this work was separated in two main parts. Firstly, with the aim to map the technological portfolio promoted by the US defense and intelligence agencies, we analyzed which technological paradigms were promoted and the development of these research trajectories over time. Thus, using bibliographic analysis, we clustered 82,239 scientific papers funded by the US national security system, published between 2009–2017 and retrieved from the Web of Science database, in research fronts. After that, we aggregated the research fronts into technological paradigms. Our analysis identified 33 technological paradigms promoted by the US defense's sectoral system of innovation, such as quantum science and graphene as fields that could generate high impact in the new generation of radical technologies. The efforts of intelligence agencies was highly concentrated on quantum science, social forecasting, computer cognition and signal processing. In a second moment, we collected 1,525,328 documents from the Web of Science about Nanotechnology, Quantum Science, and Graphene, published between 2009-2017. These field were select because of their scientific and commercial relevance. Based on this new corpus, we compared the performance of the defense-related research with other kind of funding agencies. The factors analyzed were the following: degree of promotion of international collaboration, research impact, and research prestige. As result, we found that the US National Security System promotes researches of high impact and high prestige, with inconclusive results about the promotion of international collaboration. Our research highlights the role of US security players in shaping research fields showing that they are an active and important player in the current innovative landscape, a phenomenon that still need to be studied in depth.

Keywords: Innovation; Technological paradigm; National Security; Scientometrics; Bibliographic analysis; Research evaluation

RESUMO

Desde a Segunda Guerra Mundial o sistema de defesa dos Estados Unidos tem sido um grande participante no desenvolvimento de inovações radicais em tecnologias de informação e comunicação sendo, provavelmente, as mais famosas o computador digital e a internet. Regularmente presente, a comunidade de inteligência, embora menos conhecida como propulsora do sistema inovativo dos Estados Unidos da América, é criadora de inovações de P&D. Para entender o papel e impacto pelo direcionamento de inovções através de pesquisas relacionadas à defesa e inteligência, por técnicas bibliométricas, analisamos a produção científica promovida pelo Sistema Nacional de Segurança dos Estados Unidos em campos cienificos selecionados. A pesquisa foi separada em dois vértices principais. O Primeiro, com o objetivo de mapear o portfólio tecnológico promovido pelas agências de defesa e inteligência, analisamos quais paradigmas tecnológicos foram promovidos e o desenvolvimento dessas trajetórias de pesquisa ao longo do tempo (2009-2017). Com este objetivo, através de análise bibliométrica, clusterizamos 82.239 artigos científicos financiados pelo Sistema Nacional de Segurança dos Estados Unidos, publicados no recorte temporal selecionado e recuperados da base de dados da Web of Science, em frentes de pesquisa. Em seguida, agregamos as frentes de pesquisa em paradigmas tecnológicos. Nossa análise identificou 33 paradigmas tecnológicos promovidos pelo sistema de defesa estadunidense, tais como ciência quântica e grafeno como áreas que podem causar grande impacto na geração de tecnologias radicais. Os esforços das agências de inteligência foram altamente concentrados na ciência quântica, previsão social, conhecimento computadorizado e processamento de sinais. No segundo momento, coletamos 1.525.328 documentos da Web of Science referentes à nanotecnologia, grafeno e ciência quântica, publicados também entre 2009 e 2017. Estes campos foram selecionados dada a relevância científica e comercial. Em seguida, comparamos o desempenho da pesquisa relacionada ao sistema de defesa com agências de financiamento de outra natureza. Os critérios analisados foram: o grau de promoção de colaboração internacional, nível de impacto e o prestígio das pesquisas.

Como resultado, encontramos que o Sistema de Segurança Nacional dos Estados Unidos promove pesquisas de alto impacto e alto prestígio, com resultados inconclusivos no tocante à promoção de colaboração internacional. Nossa pesquisa realça o papel dos atores de segurança dos Estados Unidos em moldar campos de pesquisa, mostrando que eles são atores ativos e importantes no atual cenário de inovação, o que precisa ser analisado em profundidade.

Palavras chave: Inovação; Paradigma tecnológico; Segurança nacional; Cientometria; Análise bibliométrica; Avaliação de pesquisa

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ARPA-E	Advanced Research Projects Agency–Energy
CIA	Central Intelligence Agency
DARPA	Defense Advanced Research Projects Agency
IARPA	Intelligence Advanced Research Projects Activity
US NSS	United States National Security System

Contents

1 Introduction

Since World War II, the United States has mobilized a considerable amount of resources for national security issues, including a related R&D strategy, focused both on the development of complex weapon systems and new means of collecting, processing and analyzing information.

The development of the digital computer had a great outburst during the WWII, and after that, innovation policies mobilized knowledge in technological parks, as the silicon valey (O'MARA, 2005). The cold war rationale provided justification for the government support of university research (ROSENBERG; NELSON, 1994). Thus, the US built the technological frontier of semiconductors with silicon technologies through actions of the Department of Defense (DOSI, 2006). The GPS was financed and is yet managed by the US Air Force.

From an analysis of the development of six general purposes technologies, Ruttan (2006, p. 162)[1] concluded that both the US and global landscape "would be vastly different in the absence of military and defense-related contributions to commercial technology development". However, at the end of the book, Ruttan poses the question about whether some constraints imposed by basic physical principles could interrupt the trajectory development promoted by US defense agencies. Notwithstanding the importance of the US National Security System (NSS) for R&D innovations there has been a dearth in systematic, in-depth views about the type and degree of scientific outputs directed by US defense and intelligence agencies.

The economics of innovation literature offers an analytic framework to evaluate the impact of the defense-related research. We draw special attention to two levels of analysis. On the one hand, the body of literature which defines the *National Innovation System* (NIS) understands that national factors, such as innovation policies and institu-

[1] Interchangeable parts and mass production, Military and commercial aircraft, nuclear energy and electric power, the computer industry, internet, space industries.

tions related to the knowledge production accumulation, define which set of actors and technologies will arise in a national context. On the other hand, the *Sectoral System of Innovation* (SSI) emphasizes the interaction between actors and technologies and the co-evolution of the mechanisms of interaction between these entities. The concepts complement each other in order to understand the innovation process which covers a set of diverse actors, either of different kind of organizations or different nationalities.

One manner to operationalize the relationship between a sectoral and several national systems, is through bibliometric techniques (also known as scientometrics). As a tool, the bibliometrics is based on the analysis of the scientific output considering the registered data and/or metadata related to a set of documents. From bibliometric data a variety of issues related to innovation may be analyzed which are related to NIS and SSI. The mapping of research fields is associated with the identification and evaluation of technological paradigms which define the set of technologies and products of a SSI; the intensity of international collaboration between the researchers is related to the exchange and knowledge production between National Innovation Systems. Furthermore, the citation impact point to the set of actors who is leading a field, representing the mechanism of selection between national systems and within a specific sectoral system. Additionally, information about funding agencies for each paper published since 2008 was made available by the Web of Science (WOS), which gives us the opportunity to understand another important actor both for NIS and SSI: the set of organizations, most of them governmental, which promote research.

Another important factor about bibliometrics has to highlighted. Nowadays, the advancement of computer processing and storage combined with the online access of bibliometrics database permits that researchers to carry out analysis based on a large corpus. Thus, while the pionneering works used sample of datasets (KESSLER, 1963; PRICE; GÜRSEY, 1975), the more recent ones executed analysis based on all available data from Web of Science and Scopus (SMALL; BOYACK; KLAVANS, 2014; WALTMAN; VAN ECK, 2012). Therefore, with a sensible cost and knowledge about big data techniques it is possible for researchers perform analysis in a great mass of documents.

Therefore, based on the history regarding the promotion of impactful technologies, combined with the potentialities offered by scientometric data, it is important to execute a meticulous analysis of the role and impact of the defense-related agencies of the US in the scientific output. The research subject is also justified given the recent developments inside the system ignited by the terrorist attacks of 09/11. Less restrictive surveillance laws were approved giving more powers for intelligence agencies to collect and analyze information. Furthermore, the national security apparatus became involved in two wars in Afghanistan and Iraq. These events had a considerable impact on the defense and intelligence budget (DAUGHERTY MILES, 2016), while a new set of agencies for the promotion of technological innovations were created; e.g., emulating DARPA located in the Department of Defense (DoD), HSARPA in the Department of Homeland Security, IARPA in the Office of the Director of National Intelligence, and ARPA-E in the Department of Energy were formed. These agencies together with the already existing security and intelligence agencies emerged as one of the largest financiers of technological research, shaping the landscape of scientific innovations and outputs.

1.1 Research problem

We conceived the following research question: What is the influence and impact of the US NSS in the development of technological paradigms? Once the measure of impact will be operationalized through citation analysis, our main hypothesis is that the US NSS have higher impact and influence than other kind of funding agencies.

General objective: Evaluate through bibliometric techniques the citation impact of the US NSS.

Specific objectives:

a) Identify the technological paradigms promoted by the US National Security System;

b) Identify the intelligence-related research inside the National Security System;

c) Compare the performance of the US National Security System vis-a-vis other kinds of funding agencies.

1.2 Thesis overview

After this introductory chapter, we bring a literature review about the following topics: firstly, the role of defense and intelligence agencies in the innovative landscape, where we identified the lack of a systematic and empirically grounded evaluation about the technological portfolio of the US NSS. Secondly, we present the literature related to the innovation process, mainly focused on the development of technological paradigms. Third, we present an analytic framework in order to analyze the impact of funding agencies in the context of both a sectoral and national system of innovation.

The results are separated in two sections, that although related, could be read independently. These two parts represent our evolution in the research process in unveiling where and how much the US NSS exercise influence in scientific fields. From the start, the lack of an empirical and comprehensive appraisal of the technological paradigms promoted by the US NSS made the task difficult. The only parameters to evaluate where this impact could be felt were oficial documents (NATIONAL SCIENCE AND TECHNOLOGY COUNCIL, 2016; OFFICE OF THE DIRECTOR OF NATIONAL INTELLIGENCE; UNITED STATES INTELLIGENCE COMMUNITY, 2014) or qualitative evaluation (GODFREY, 2016) that pointed the importance of some areas. Thus, the first section brings the mapping of the technological portfolio promoted by the US NSS and is presented in Maciel, Bayerl and Kerr Pinheiro (2019)[2]. Considering the big science fields, most of the research promoted by the system is within the field of Physical sciences and engineering. Furthermore, we identified the main technological paradigms promoted by the US defense's sectoral system of innovation, such as quantum science and graphene as

[2]The article can be acessed on https://link.springer.com/article/10.1007/s11192-019-03148-2

fields, that could generate high impact in the new generation of radical technologies.

The second part, present in the body of this document, brings the measure of the impact of the US NSS in the fields of Graphene, quantum science, and nanotechnology. These fields were chosen since they represent basic and foundational research of new physical phenomena which could generate high impact innovations. Besides that, the choice considered also methodological issues. We preferred to choose few fields but with broader coverage in order to try to keep as much as possible the science structure if compared with a global map of science which would be built from all the Web of Science dataset.

It is important to note that this thesis may be read independently regardeless of the findings presented in Maciel, Bayerl and Kerr Pinheiro (2019) without jeopardizing the understanding of the content. Nonetheless, we strongly encourage the reading of the published article before the body of the thesis for two reasons: firstly, the reader will have contact with the large scope of the technical research innovations promoted by the US NSS. Second, the technological maps created give context about the research fields analyzed in the the body of the thesis.

2 Literature review and research questions

In this section we bring the literature review. We start with a general appraisal of the work concerning the role of defense and intelligence agencies in technological development and innovation. After that, we bring the literature about innovation studies related specifically to the sectoral systems of innovation (SSI) and National Innovation System(NIS). In parallel, we delineate which kind of scientometric data might be used in order to analyze empirically the evolution of both systems. Finally, we built an analytical framework to evaluate the impact of government initiatives in the scientific development.

2.1 US national security funding for research innovations

The role of the US defense sector in promoting innovations has been sparsely studied. From the investment side, Mowery (2012) noted that despite the considerable volume of literature about innovation systems there are few that approach defense-related investments in innovation. This contrasts sharply with the fact that defense-related R&D and procurement programs have exercised enormous influence over innovations in the ICT sector since WWII. The overall indications are that defense-spending affects scientific research in multiple ways. Malik (2018) measured the impact of defense expenditure on high-technology exploitation, demonstrating that defense-spending increased scientific output in publications and patents. Libaers (2009) further showed that DoD grants are linked to higher involvement of academics resulting in a higher number of industrial partners and more consultancy work, indicating that DoD-funding leads to a shift in the focus of research conducted. Plummer and Gilbert (2015) associated defense activity with 'closed science', when analyzing the role of defense agencies' funding of entrepreneurship. They concluded that funding defensed-based research for universities decreases regional entrepreneurship activities in the short-term, however is positively related to entrepreneurship in the long-term. A more recent work (CORREDOIRA; GOLDFARB; SHI, 2018) analyzed patents granted from the United States Patent and Trademark Office (USPTO) and found that the defense agencies, such as the US Army, US Air Force, US Navy and DARPA, together with the National Institutes of Health produces breakthrough inventions. Together with other studies about spill-over effects from military to civilian innovations and research (ACOSTA *et al.*, 2013; KAS *et al.*, 2012; OLIJNYK, 2018), these findings indicate that defense-related funding impacts the way scientific research is conducted and the development of technological innovations.

Other qualitative studies bring evidence about the importance of the US NSS in the innovation landscape and discuss the nature of the system. Mazzucato (2014) use technological endeavor of the US defense sector in the context of the *Entrepreneurial State*, where the state sets the innovative landscape and takes technological risks which the private sector is not willing to take.

The reasoning of the *Hidden Industrial Policy* is offered by Block (2008) who explains that along the years, the executive body of the United States has been using the defense sector and the national security issues, which imply secret projects and more freedom of action, in order to promote industrial policy without damaging the discourse of free-markets. This conception explains in part the difficulty in replicating the defense model for a civil initiative, i.e, when an initiative becomes of public scrutiny.

Third, Weiss (2014) rejects the defense endeavor as an innovation/industrial policy, explaining that the commercial' posture of the US National Security State is aimed to achieve the technological superiority for supporting American supremacy and not for promoting economic competitiveness. This last perspective is in accord with Brito (2015), which built the historical account of the creation of the internet by DARPA from the perspective of the *Informational State*, where the internet is a tool for the exercise of the *Informational Power*.

Besides the traditional and big organizations inside the US Department of Defense, such as the US Army, US Air Force, US Navy, and DARPA, the US national security apparatus also comprises organizations with the aim to collect, process and analyze information about threats against the US. This role is covered by the term *intelligence*. There are numerous intersections between intelligence activities and the field of information science (IS), to the extent “that is indeed difficult to find any topic in information science and technology not relevant to intelligence, information warfare, and national security, or conversely” (DAVIES, 2005, p. 313). The trend in the specialized literature concerning intelligence and technology is divided along two main branches: On the one hand, there is interest in understanding how technology could affect the intelligence systems, either concerning new means of collection, processing and analysis of information by the intelligence practitioners or the generation of new threats (VOGEL; KNIGHT, 2015; WARNER, 2012). On the other hand, there are case studies about economic and technological espionage (COCHRAN, 2003; MACRAKIS, 2004).

Consequently, the role of national intelligence agencies in academic innovations and research has received much less attention (CRONIN, 2011) in line with the role of US defense funding more generally. Nevertheless, there are historical accounts about development of technologies through intelligence agencies. For instance, in order to carry out surveillance activities regarding the Soviet Union, the Central Intelligence Agency, together with the private firm Lockheed Company’s Burbank, pushed the technological frontier in aviation of high altitudes developing the U2 aircraft during the 1950s, which also demanded more advanced photography devices (RICHELSON, 2013). In parallel, the Central Intelligence Agency (CIA) launched the Corona Project, which supplied photographs from satellites with better geographical coverage than those offered by the old U2 (CENTRAL INTELLIGENCE AGENCY, 2013).

More recently, the CIA created in 1999 a public venture capital, the In-Q-Tel, with the objective of promoting the development and adaptation of technologies that are commercially viable. The government invests and participate in the management of small firms. Thus, a public-private network is supported where financial tools are used to promote technologies of interest to the intelligence activities (KELLER, 2016). The In-Q-Tel example has been successful to the extent that the Department of Defense created its own venture capital agency, the OnPoint technologies (WEISS, 2014).

2.2 Research as sectoral system of innovations

To understand the impact of the US national security system and other kinds of funding initiatives on technical research innovations, we consider research as a sectoral system of innovations (SSI) (MALERBA, 2002). This implies the analysis of the patterns of technical innovations, acknowledging the fact that different sectors may follow disparate logic in their development and experience shifts in activities over time. Among the building blocks of interests the following are considered herein: knowledge and learning processes, basic technologies and complementarities, mechanisms of interactions, processes of competition and selection.

The sectors differ based on the *Knowledge base and learning process*, since "one knowledge domain refers to the specific scientific and technological fields at the base of innovative activities in a sector" (MALERBA, 2002, p. 251). This evolutionary process of knowledge accumulation can be captured in the form of technology trajectories which can be understood as "the pattern of 'normal' problem solving activity (i.e. of 'progress') on the ground of a technological paradigm" (DOSI, 1982, p. 152). In a similar way to scientific paradigms (KUHN; HAWKINS, 1963), the "normal route" of a technological paradigm (TP) is often marked by discontinuities but is also selective, since the next set of problems that have to be solved leaves other questions unresolved.

Technological trajectories are often marked by shifts in the knowledge accumulation, which point to changes inside a TP. In Maciel, Bayerl and Kerr Pinheiro (2019), we considered as basic unit of analysis of these changes the disparate, although interconnected research fronts (RF's), which are "discontinuous, starting and ending abruptly as scientists move from one puzzle to the next" (MORRIS *et al.*, 2003, p. 414). Figure 1 illustrates this process in the evolution of technological trajectories inside a technological paradigm. With an average duration of approximately 5 years, the research front capture the short-term change in the technological trajectories. Furthermore, we could also consider as the basic unit of analysis of technological paradigms the scientific taxonomies as proposed by Price and Gürsey (1975). In this case, the interest is on the more stable subjects and less transient research topics than those captured in the concept of research fronts.

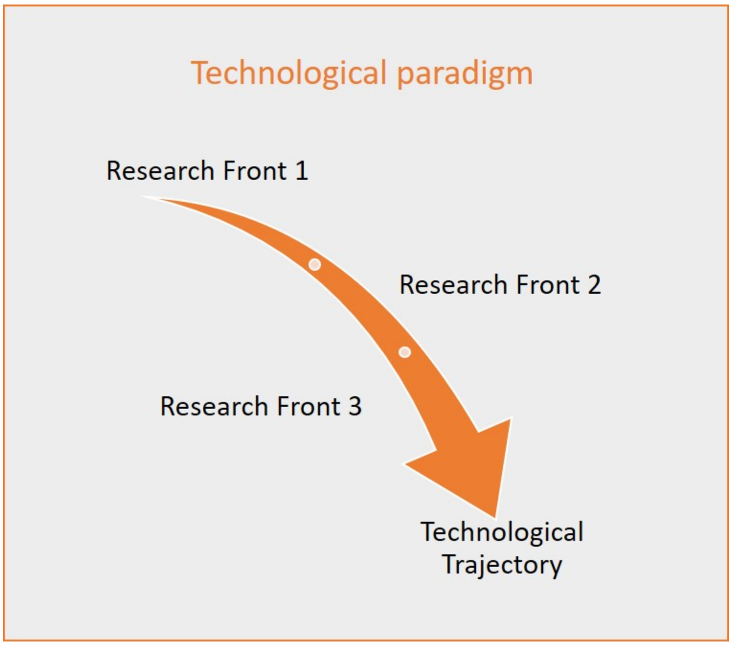

Figure 1: Shifts in trajectories within technological paradigms

Another characteristic which differs between SSI's is the *Mechanisms of interaction* between the several type of organizations: public, private, universities, venture capital initiatives and so on. An important mechanism of interaction which is possible to analyze from bibliometric data is the international collaboration in science. As shown by Ribeiro et al. (2017), the number of articles co-authored by organizations of different countries has been increased over time, however, the network presents a hierarchical nature with few hubs which mobilize more connections than the vast majority of the other ones.

To understand the developments of international collaboration in research innovations funded by the US NSS, we therefore aim to answer the following research question (RQ) with its respective hypothesis (H):

RQ1: Does the type of funding (defense, non-defense) have an influence on promotion of international collaboration?

H1: Defense-related agencies are less proned to promote international collaboration. We account for this hypothesis since the defense research are related to security issues

Another element of an SSI is the *process of competition and selection*. The mechanisms of interaction over time imply a process of network formation, which consists on a "historical outcome of processes of variation (at the micro level) and selection (at the macro level)" (LEYDESDORFF; AHRWEILER, 2014, p. 2361). Thus we might conceive the existence of forces within a technological paradigm related to knowledge accumulation and production, mainly executed by research organizations and private companies, as well as outside forces of selection that work together to change research trajectories. Therefore, governmental agencies could work as a mechanism of selection, since as institutions they select research performers, provide policy frameworks that guide research efforts and in injecting external money which impact market conditions. They therefore possess vital impact of how technical research trajectories develop over time (LERNER; STERN, 2012). Exemplifying about the aircraft sector, (NELSON, 1995, p. 64) explain that the "military is an important customer, as well as the airlines. Thus the evolution of aircraft at least partially reflects military demands and budgets, as well as civilian".

In this research, we operationalize the process of competition and selection inside a technological paradigm through the analysis of the citation impact. A stream of literature show that international collaboration increase the country citation impact (LEYDESDORFF; BORNMANN; WAGNER, 2019; WAGNER; JONKERS, 2017; WAGNER *et al.*, 2018). However, the analysis at the paper level identified that international collaboration produces less novel and more conventional knowledge (WAGNER; WHETSELL; MUKHERJEE, 2019). Thus, we have another two research questions:

RQ2: How Does the promotion of international collaboration increase the impact of the funding agency?

H2: The higher the international collaboration intensity promoted by the funding agency the higher the citation impact.

The relation of funding and research impact is somewhat of ambiguous. On the one hand, analysis at document level based on the funding acknowledgment data, show a positive association between the presence of funding and impact. That is present in the work of Gök, Rigby and Shapira (2016), which showed that the presence of funding is associated with highly cited research, and furthermore, that "there is indeed a hierarchy of funding sources in terms of impact and this hierarchy is inversely related to their relative frequencies" (GÖK; RIGBY; SHAPIRA, 2016, p. 724). Similarly, the analysis of patents granted in the US carried out by Corredoira, Goldfarb and Shi (2018, p. 1796) showed that patent "seminality appears confined to a few agencies and is mostly present with government funding of academic research".

On the other hand, analysis aggregated at country level has different results. Liang and Liu (2018) asserted that government sponsored network can be a negative impact on innovation performance and other stream of literature show that P&D investment are negatively correlated with the citation impact (LEYDESDORFF; BORNMANN; WAGNER, 2019; WAGNER; JONKERS, 2017; WAGNER *et al.*, 2018). However, we tested for differences in type of funding agencies in order to answer the following research question:

RQ3: Does the type of funding (defense, non-defense) influence the impact the funding agencies?

H3: The US defense agencies have more citation impact than other kind of funding agencies.

Additionally, we aim to delineate the flow of citations between funding agencies in order to answer the last two research questions:

RQ4: Where does defense funded research get ideas from (defense/non-defense?) and where does it have impact (defense/non-defense?)?

RQ5: What is the reputation of the defense agencies in the citation network?

2.3 National Innovation System and sectoral system of innovation: an analytical framework

The sectoral system of innovation concept implies in a mid-level of analysis based on the interaction between organizations and technologies. However, the contrast between countries concerning the innovation process is explained by the difference between national factors of knowledge building, such as innovation policies and institutional factors (FREEMAN; SOETE, 1997, chapter 12). These differences impact mainly on the composition of private and governmental actors which participate in the innovation process and on the portfolio of technologies which the country intends to develop (NELSON, 1993). The national sphere is also important to consider, once the iterative learning which is necessary to the innovative process depends on a environment with few cultural and linguistic barriers (LUNDVALL *et al.*, 2002). Nonetheless, the sectorial change at the paradigm level and exchange of information between sectors show patterns of similarity regardless of the nationality (MALERBA; ORSENIGO, 1997; PAVITT, 1984).

Based on this, figure 2 show the process of interaction between the two hypothetical NIS and a specific SSI. The interaction between countries is mediated by the technological paradigm which determines the knowledge base of a sectoral system of innovation. In the case of interest of this study, we claim that the identification of the technological paradigms may be achieved from the analysis of scientific papers. Consequently, we consider the scientific publication as a result of a twofold process. The knowledge generation by the research performers, and the selection activities by the country's science and innovation policy.

Therefore, these elements presented on figure 2 will be considered to evaluate the impact of the US NSS in the selected technological paradigms.

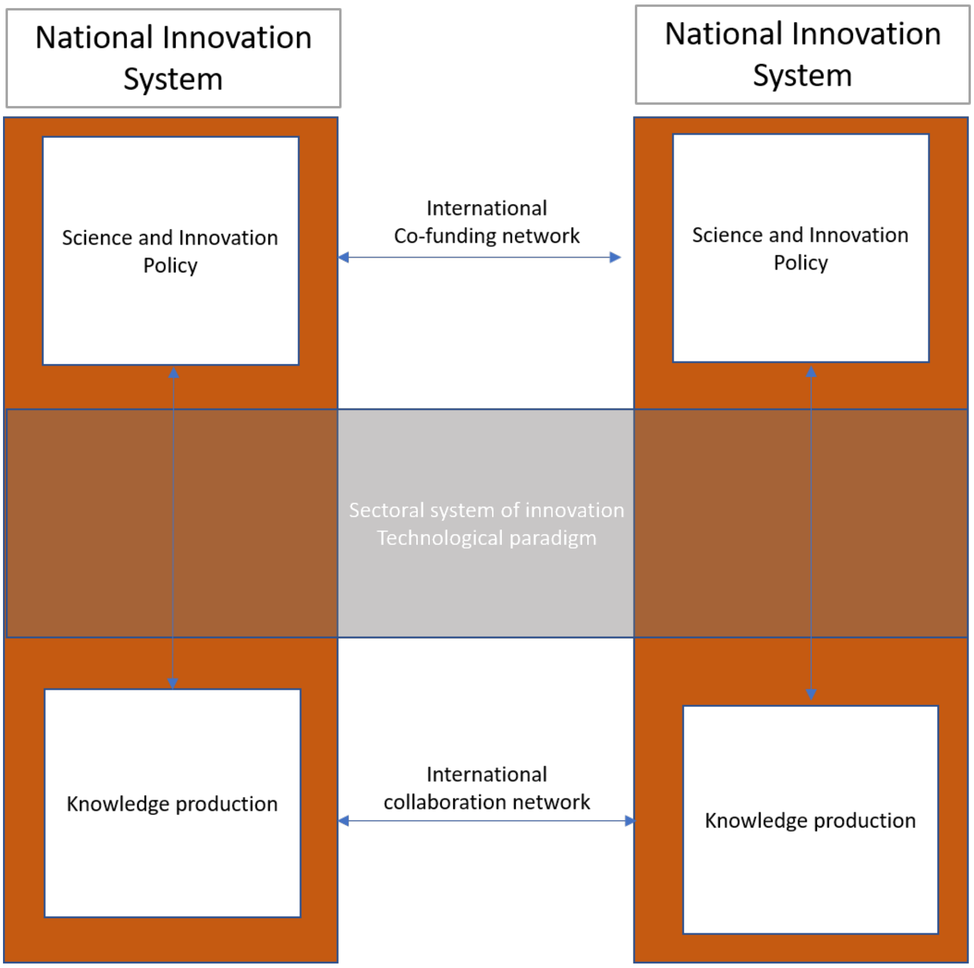

Figure 2: Framework NIS and SSI

3 Methods

3.1 Study approach

Our method consists of two main stages. Firstly, we clustered the documents in scientific taxonomies, and after that aggregated the taxonomies in technological paradigms. We considered each technological paradigm as a product of different sectoral innovation systems. Secondly, we built metrics of funding impact for each technological paradigm.

3.2 Data and data collection

To evaluate the impact of the US NSS on the selected technologies, we built a subject-based query. We took into consideration the findings of Klavans and Boyack (2011) concerning the difference between local maps (which are built from a specific literature retrieval) and global maps of science (which are built from a complete dataset). According to the authors, local maps would be imprecise because the lack of some documents may not generate the due context of the researched literature. In order to mitigate this pitfall, we took the following measures. Firstly, we considered evaluating the impact on few fields, however, using queries which cover them largely. Secondly, following the recommendations of Klavans and Boyack (2011), we identified the subject of references highly cited which were not presented in the corpus and proposed an additional query in order not lose the scientific context of the field.

Thus, we selected the following fields *Graphene*, *nanotechnology* and *Quantum Science*, since there are fields related with the (re)discovery of physical limits, and in this sense, with great importance for the innovative landscape in general, and for national security reasons in particular. From the preliminary analysis of references we checked that the following subjects were presented in the highly cited references: *topological insulators*, *Superconductivity*, and *Semiconductivity*. Then, we created an additional query retrieving this terms.

Some background about these fields is necessary. The graphene is the thinnest and strongest material ever measured, being known by its thermal and electrical conductivity (GEIM, 2009). Given its importance for defense issues, in December of 2017 the European Defense Agency hosted a meeting in order to carry out a new study about the future applications of graphene in the military domain and its impact on the European defense industry (EUROPEAN DEFENSE AGENCY, 2017). Report commissioned by the US Army Research Laboratory indicate that research on graphene could generate benefits to the american soldier, offering “more efficient power electronics and communication systems, transparent and flexible electronics, and wearable electronics" (DUBEY *et al.*, 2012). From a commercial perspective, the carbon nano tubes, that are seamless cylinders of one or more layers of graphene, have the potential to feel its impact on industries such as composite materials, coatings and films, microelectronics, energy storage and environment, biotechnology (DE VOLDER *et al.*, 2013).

Similarly, the development of *quantum Science* science, which is based on principles of quantum mechanics, may impact several fields, such as sensing and metrology, communication, simulation, and computing. One field related to national security issues that the quantum information may be a game changer is cryptography. Throughout history, the cryptography advantage alternated between two sides. The cipher creators achieved some advantage with a new technique which prevailed for some time until the cipher breakers acquire the new knowledge to break it. This process is repeated time after time. However, comparing the nation states the situation has been stable since World War II. As explained by Davies (2005, p. 329), "isolated Second World War successes like ULTRA and MAGIC, its American equivalent in the Pacific, or retrospective cryptanalytical successes like VENONA during the Cold War, highly secure national communications systems have rarely been broken". It is not coincidence that the those success was a result of the advance of the digital computer which generate a strong impulse by innovation policies from US defense agencies in the context of the cold war(MOWERY; ROSENBERG, 1998; O'MARA, 2005).

Finally, *nanotechnology* cover the field of research at nanoscale science, defined in the size range of 1 to 100 nanometers, being the nanometer a billionth of a meter (10^{-9}). As stated by Silberglitt et al. (2006, p. 10) the global investiment on nanotechnology has been increased, based on "the belief that the ability to understand and affect atomic and molecular interactions at the nanoscale is both a prerequisite and an enabler for a host of technological capabilities" in a variety of applications, such as "smart, multifunctional materials to designer drugs and new generations of information and communications systems".

Therefore, we retrieved 1,525,328 documents[3] from the Web of Science core collection published in the period of 2009-2017. For matching references with the document identifier existent in our corpus and creating a citing-cited pair list between a document and its references, we followed the general principles of Olensky, Schmidt and van Eck (2016). To test the robustness of our matching algorithm, we compared the number of citations a document received in the corpus with the number offered by the web of Science. We verified that the citation counts in the dataset based on our matching algorithm is highly correlated with the number presented in the WoS database ($r = .94$, 95% CI [.94, .94], $t(1525326) = 3,394.69$, $p < .001$).

3.3 Identifying taxonomies and TP's

3.4 Indentificando taxonomias e paradigmas tecnológicos

We also included in the analysis the external references which were not present in the corpus, because according to Waltman, Boyack and Colavizza (2019), the inclusion of external references in the direct citation method, called extended direct citation, increases the accuracy of clustering solutions offering a performance similar to bibliographic coupling. Besides that, we considered that the choice of the direct citation method is more appropriate to evaluate the impact represented by citation counts. Thus, we will have a cluster solution which is built around the most cited papers. Therefore we built a network of 2,018,648 nodes (including documents retrieved and external references) and 72,923,244 links.

This network file was used as input for the Leiden algorithm (TRAAG; WALTMAN; ECK, 2019) with resolution of 6×10^{-5}. The Leiden algorithm was launched recently and it is a improvement of the Smart Local Moving algorithm concerning accuracy and speed of processing. Clusters with size below 80 were excluded from analysis

[3]The complete query is the following: quantum OR "Majorana" OR qubit* OR "Bose Einstein Conden*" OR "Topological insulator*" Graphene or "carbon nano*" OR superconduct* OR semiconduct* OR nano*

in order to mitigate the effects of the building of a local map. As a result, we identified 2,577 taxonomies (on average, 488.54 documents by taxonomy).

Technological Paradigms were identified using the clustering of the taxonomies as input, considering their textual similarity. The BM25 similarity between each pair of clusters was calculated following equations given by Boyack and Klavans (2014). The taxonomies were considered as documents, and their contents were indexed from the title and abstracts of the papers included in the taxonomies. The pairs were filtered using Top-15 similarity (BOYACK; KLAVANS, 2010). We ran the leiden algorithm with a resolution of 0.6.

We tested several resolutions to find a result that allowed clearly identifiable groupings of technologies. For this end, we analyzed mainly the distribution of keywords related to quantum technologies, such as *quantum cryptography* or *quantum computer*. We considered that a minimum resolution, which kept these technologies separated was "ideal" and could also give a sensible solution for other paradigms. The heat map present in the figure @ref(fig:heat map-TP) show the BM25 similarity between some selected queries and the technological paradigms. The values were achieved calculating the BM25 similarity at the taxonomic level and averaged at the paradigm level.

From the figure, it is possible to visualize that some queries presented well defined results with high values concentrated in a specific technological paradigm. In turn, the words associated with nanotechnology have high values in the technological paradigm 4, and a value around expected in the technological paradigm 1. However, since paradigm 4 is specific concerning Graphene, for this analysis we labeled paradigm 1 as *nanotechnology*, but acknowledging that field expertise is necessary for a better understanding of the technological content.

Therefore, considering only the documents retrieved in the Web of Science and excluding the external references, the taxonomy-based classification offered coverage of 82.54%.

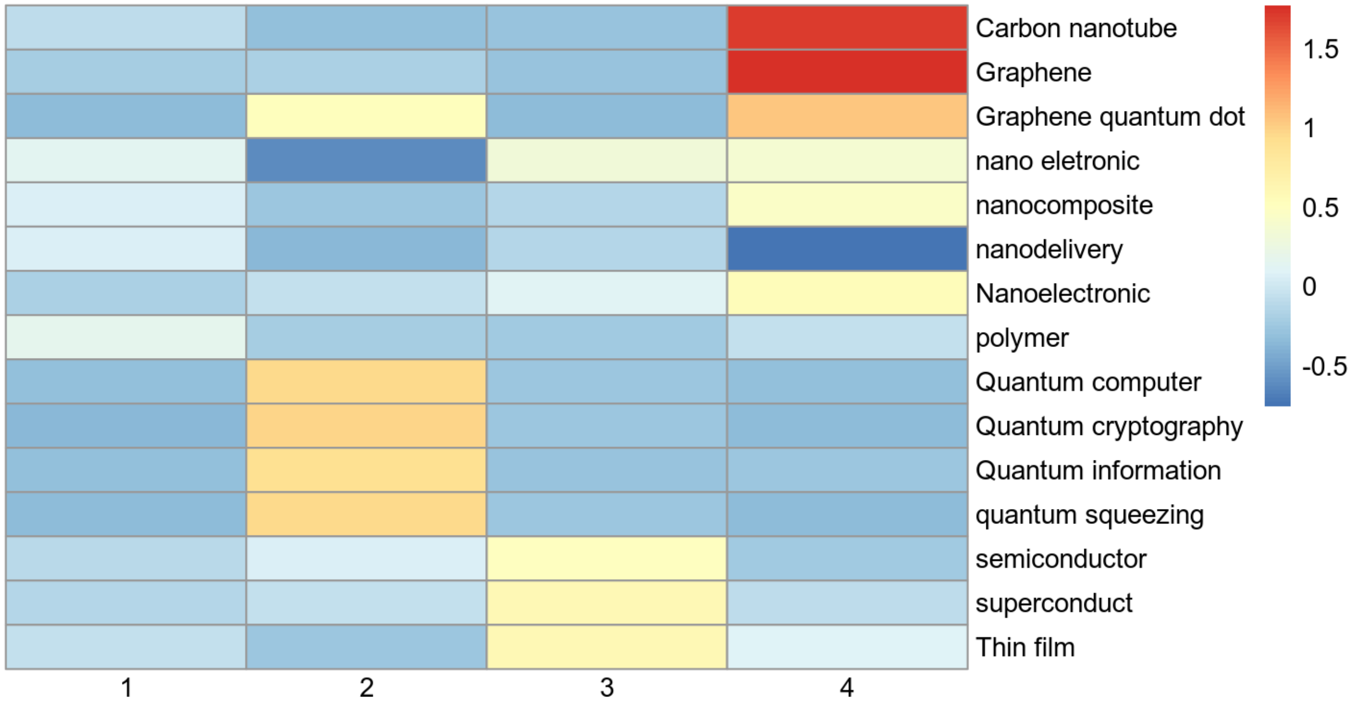

Figure 3: Identification of technological paradigms from an information retrieval strategy. The x-axis represents the numbering of the technological paradigms identified. The y-axis shows the query used.

3.5 Data cleaning and variables used

Funding classification refers to the identification of various types of funding agency involved in the process of research promotion. In this study, we used the field tag "FU" which is processed by the WoS from the funding acknowledgment text in the documents in order to obtain the funding agency and grant number. The Web of Science was used instead of the Scopus since it has a higher coverage of funding data (KOLSTAD; ÅRTHUN, 2018). There are some imprecisions in the WoS-field of funding agency in the data. Thus, we created a dictionary-based algorithm to match funding agencies with part of text presented. We paid special attention to the 1071 funding agencies ranked by the Web of Science in the InCites platform.

For each funding agency, we executed searches to identify the country. The exceptions are international agencies, where the country field is labelled as "international".

Subsequently, we classified the funding agencies according to their type in the following categories:

a) Governmental (coded as “GOV”): Public organizations at any governmental level (federal, state or municipal). We worked with an aggregation at the departmental level. Thus, public laboratories are unified with their respective main agency;

b) Corporate (coded as “CORP”): any private organization. Universities are included in this category independent of whether they are public or private organizations.

c) National Security funding (coded as “DEFENSE”): This category is a sub-group of governmental funding which comprises the US National Security agencies. The aggregation is the same as in the case of the governmental funding. For instance, the US army laboratories are all aggregated in the label of US Army.

d) International: International organizations which are supranational (such as the European Union) or cover at least two countries (such as the *United States Israel Binational Science Foundation*).

e) No funding: documents which do not have information of funding. However, this category needed better refinement in order to classify no funding research according to its respective country. Thus, for each paper without funding acknowledgement a no funding entity is created whose country’s affiliation is based on the country of the researchers. If a paper has organizational address in two or more countries, two or more no funding entities are created. Thus, we consider that there is no paper without any kind of support, either personal funds of researchers, or in the last instance, the organizational budget of the research organization.

The table 1 show the descriptive statistics about these categories. A lot of effort was made to classify as many funding agencies as possible, nonetheless, in the end there is still have some unstructured text which does not denote unambiguously an individual funding agency, such as “National Research Foundation”.

Table 1: Summary of data about funding categories at document level

Category	# documents	Fractional counting
NO CLASSIFIED	746,258	463,564.83 (30.39%)
GOV	734,572	523,665.72 (34.33%)
NO_FUNDING	447,020	447,020.00 (29.31%)
CORP	99,497	46,358.53 (3.04%)
INTERNATIONAL	49,783	24,644.84 (1.62%)
DEFENSE	39,190	20,074.09 (1.32%)

Frac_count is the variable which represents the *funding intensity* of each funding agency. A method usually calculated to measure the co-authorship network (LEYDESDORFF; PARK, 2017; PERIANES-RODRIGUEZ; WALTMAN; ECK, 2016) the reasoning of the fractional counting is to distribute the responsability for each article between the organizations which participate in its elaboration. In our case, for each paper an agency receives the credit $\frac{1}{n}$, where n is the number of funding agencies which are present in the paper. The text not classified in our corpus were also used, in order to give more conservative estimates about the funding impact of the classified agencies.

Another variable is the *international intensity* of the research promoted by the funding agency. Each paper is tagged as international if it has at least two different countries in the affiliation field; national otherwise. Each funding agency gets a proportional share of the international collaboration. For instance, in an international paper with two funding agencies, each funding agency will receive half of the counting of the international collaboration. The fractional number of international papers was used to calculate the percentage of all papers that are internationally co-funded, by funding agency.

From the bibliometric perspective, we consider citation as a measure to identify process of competition and selection of the actors within a sectoral system of innovation. From the citation we can identify which actors have recurrently more impact on a field. From the side of the funding agencies, we can identify which kind of agency is setting the agenda of research and anticipating the development of technological trajectories. The citation may be used both as a measure of impact as well as a measure of reputation.

Representing the impact of the funding agency, we calculated the Field weight citation impact (FWCI) which refers to the ratio of citations a document received relative to the expected world average for the documents with the same characteristic (such as subject field, publication type, and publication year). For example, a score of 1.50 means the publication receives 50% more citations than the world average, a score of 0.50 means it receives 50% less than the world average. The FWCI values for funding agencies are derived by aggregating the article-level values of received citations between the funding agencies. More formally, as presented in Wagner et. al (2018),

$$fracFWCI \equiv \frac{\sum_{i=1}^{N}\left(\frac{C_i}{e_i} f_i\right)}{\sum_{i=1}^{N} f_i} \tag{1}$$

where c_i equals citations received per publication i within a specific time window; e_i equal expected number of citations received by publication i whithin the specific time window, based on all similar publications; f_i proportion of funding agency on publication i. In their paper, Wagner et. al (2018) used the citations received by a paper within 5 years since the publication. In our case, we will evaluate three different time windows. Thus, the FWCI_3 is the variable which considers the citations received within 3 years and represents the funding agency short term impact. The FWCI_5 cover a 5 year time windows and represent a medium-term impact.

3.6 Model Specification: measuring international collaboration and impact

We calculated the independent variable for each year, thus, we have a panel data structure which allows for observations over time. For answering RQ1 to RQ3, we built two random effects models. Both of the models are a three level hierarchical model, where the observations at each year(first level) are aggregated by funding agency (second level) which are in turn nested in countries (third level). Therefore, we consider differences between the organizations which will share a random intercept according to the country, i.e., we take in consideration the national diferences. Our main contextual variable of interest at the funding agency level is the funding type, and the dependent variables are measured at level 1. For all the models, we used only documents of the type article, proceedings paper, or review, in order to keep the comparisons along a more homogeneous dataset. Likewise, we assumed a mininum size threeshold as a relevance criteria. Thus, for all the models and for each technological paradigm, only organizations which have at least one year with a minimum fractional count of 20 were keept in the dataset.

In order to answer the RQ1, the dependent variable is the international collaboration. The funding category and fractional count are the independent variables. Time and fractional count are used as control. This analysis cover the period of 2009-2017. The table 2 show the descriptive statistics of the data used to evaluate the promotion of international collaboration.

The second model was built to answer RQ2 and RQ3, where the FWCI is the dependent variable. In this model we use the Random Effect Within Between model (REWB) which explicitly separates within and between effects (BELL; JONES, 2015). As explained by Schmidt-Catran and Spies (2016), “a within effect is based solely on variation within units over time, and between effects are based on variance between units”. In this case, the international collaboration became a explanatory variable, together with the funding category. Time and fractional count are used as control. The short-term impact is measured considering citations within a 3 year time window after the publication year. The descriptive statistics for ther shor-term impact is shown in table 3, where the period of analysis cover the years from 2009 to 2014. On the other hand, the medium-term impact consider the citations within a 5 year time window with the descriptive statistics in table 4, and covering the years from 2009 to 2012.

Table 2: Descriptive statistics: international collaboration as dependent variable

	# observations	# agencies	# Countries	Avg. international collaboration	Avg fractional counting
Nanotechnology					
Total	2036	231	53	0.30 (0.17)	120.91 (366.34)
GOV	1170	134	40	0.29 (0.17)	137.51 (452.27)
NO_FUNDING	432	48	48	0.30 (0.16)	160.59 (260.82)
CORP	380	43	13	0.31 (0.20)	28.53 (23.06)
DEFENSE	54	6	1	0.24 (0.07)	93.73 (59.72)
Quantum Science					
Total	1395	159	41	0.37 (0.19)	86.74 (174.91)
GOV	799	92	31	0.39 (0.19)	99.13 (212.91)
NO_FUNDING	342	38	38	0.28 (0.14)	95.37 (124.59)
CORP	200	23	10	0.47 (0.20)	23.71 (19.95)
DEFENSE	54	6	1	0.33 (0.07)	82.23 (54.72)
Thin Films					
Total	1022	117	37	0.33 (0.18)	75.60 (135.74)
GOV	629	73	28	0.32 (0.18)	76.88 (155.90)
NO_FUNDING	306	34	34	0.29 (0.15)	82.35 (104.77)
CORP	51	6	5	0.57 (0.23)	20.23 (9.37)
DEFENSE	36	4	1	0.28 (0.07)	74.17 (27.78)
Graphene					
Total	1097	125	32	0.29 (0.18)	73.60 (209.23)
GOV	721	83	28	0.29 (0.18)	80.51 (251.24)
NO_FUNDING	234	26	26	0.26 (0.16)	78.50 (95.38)
CORP	106	12	9	0.39 (0.26)	18.52 (12.56)
DEFENSE	36	4	1	0.27 (0.08)	65.69 (31.40)

[1] This analysis cover the period of 2009-2017

Table 3: Descriptive statistics related to short term impact

	# observations	# agencies	# Countries	Avg. international collaboration	Avg fractional counting	Avg. FWCI
Nanotechnology						
Total	1242	213	48	0.27 (0.16)	121.42 (325.89)	0.98 (0.32)
GOV	732	127	39	0.27 (0.17)	132.72 (394.51)	0.98 (0.31)
NO_FUNDING	258	43	43	0.28 (0.14)	170.90 (243.12)	0.77 (0.21)
CORP	216	37	13	0.29 (0.18)	27.81 (19.28)	1.17 (0.34)
DEFENSE	36	6	1	0.21 (0.05)	98.52 (58.51)	1.33 (0.22)
Quantum Science						
Total	863	148	41	0.35 (0.18)	92.67 (170.45)	0.99 (0.39)
GOV	503	87	30	0.37 (0.19)	101.80 (204.28)	1.00 (0.33)
NO_FUNDING	228	38	38	0.27 (0.13)	101.13 (123.80)	0.73 (0.20)
CORP	96	17	7	0.45 (0.21)	27.25 (22.19)	1.28 (0.46)
DEFENSE	36	6	1	0.31 (0.07)	86.09 (53.30)	1.74 (0.40)
Thin Films						
Total	637	108	37	0.30 (0.17)	82.11 (132.16)	0.95 (0.29)
GOV	380	65	26	0.30 (0.16)	84.28 (152.56)	0.98 (0.27)
NO_FUNDING	204	34	34	0.26 (0.12)	86.65 (103.27)	0.80 (0.19)
CORP	29	5	4	0.62 (0.20)	22.40 (8.45)	1.28 (0.38)
DEFENSE	24	4	1	0.25 (0.05)	81.33 (21.62)	1.42 (0.16)
Graphene						
Total	625	106	29	0.26 (0.17)	71.41 (165.44)	0.99 (0.42)
GOV	405	69	23	0.26 (0.16)	76.30 (197.92)	1.01 (0.36)
NO_FUNDING	144	24	24	0.22 (0.13)	78.73 (85.79)	0.72 (0.24)
CORP	52	9	7	0.38 (0.28)	16.09 (11.18)	1.20 (0.66)
DEFENSE	24	4	1	0.24 (0.09)	64.93 (28.29)	1.68 (0.50)

[1] This analysis cover the period of 2009-2014

Table 4: Descriptive statistics related to medium-term impact

	# observations	# agencies	# Countries	Avg. international collaboration	Avg fractional counting	Avg. FWCI
Nanotechnology						
Total	675	171	46	0.27 (0.16)	129.82 (284.86)	0.98 (0.32)
GOV	406	103	38	0.27 (0.16)	133.02 (330.96)	1.01 (0.31)
NO_FUNDING	164	41	41	0.26 (0.13)	174.82 (236.39)	0.77 (0.20)
CORP	81	21	9	0.32 (0.19)	32.79 (17.07)	1.17 (0.34)
DEFENSE	24	6	1	0.19 (0.04)	95.74 (55.37)	1.38 (0.26)
Quantum Science						
Total	511	128	39	0.34 (0.17)	100.44 (167.10)	0.98 (0.41)
GOV	299	75	30	0.37 (0.18)	104.36 (193.12)	0.98 (0.33)
NO_FUNDING	144	36	36	0.25 (0.12)	115.88 (139.81)	0.74 (0.22)
CORP	44	11	5	0.45 (0.15)	33.64 (24.85)	1.32 (0.50)
DEFENSE	24	6	1	0.30 (0.07)	81.40 (51.12)	1.84 (0.45)
Thin Films						
Total	379	95	33	0.29 (0.16)	90.39 (131.27)	0.98 (0.30)
GOV	223	56	24	0.30 (0.17)	88.96 (146.67)	1.01 (0.29)
NO_FUNDING	124	31	31	0.25 (0.12)	102.02 (115.79)	0.81 (0.19)
CORP	16	4	3	0.56 (0.18)	26.52 (7.51)	1.34 (0.28)
DEFENSE	16	4	1	0.23 (0.04)	84.00 (19.05)	1.46 (0.20)
Graphene						
Total	332	83	27	0.25 (0.15)	70.08 (122.47)	1.01 (0.43)
GOV	212	53	22	0.26 (0.15)	70.80 (143.55)	1.03 (0.37)
NO_FUNDING	88	22	22	0.21 (0.13)	79.45 (79.98)	0.74 (0.25)
CORP	16	4	4	0.41 (0.22)	19.59 (8.05)	1.38 (0.33)
DEFENSE	16	4	1	0.20 (0.07)	59.53 (24.07)	1.83 (0.61)

[1] This analysis cover the period of 2009-2012

3.7 Network Flow and PageRank centrality

In order to answer the RQ4 and RQ5, we built the citation network between the funding agencies. Since an article may contain several funding agencies, the principle of fractional counting is also used to identify the flow of knowledge promoted by the funding agencies. Therefore, for each article i which cites the article j, the weight between the funding agency k present in i and the agency p present in j is calculated as follow:

$$FC_{k_i p_j} = \frac{1}{n_i \times n_j} \tag{2}$$

Where n_i equals the number of funding agencies present in article i and n_j the number of funding agencies in j. The mapping of these flows aim to answer the RQ4. To answer the RQ5, about the prestige of the research promoted by the US defense agencies, we ran the PageRank algorithm. This measure takes into account not only the number of received citations of a specific funding agency, but also the reputation of citing institutions (MASSUCCI; DOCAMPO, 2019).

4 Results

In this section we present our results. We start examining the influence of the funding categories on the promotion of international collaboration and citation impact. Finally, we present the results about the research reputation of the funding agencies with special attention to the defense-related research.

4.1 Promotion of international collaboration

The RQ1 is concerned about the differences between the funding agencies according the promotion of international collaboration. The estimated results are shown in table 5. The Governmental and corporation funding have a positive significative effect in all the technological paradigms. Otherwise, the defense-related research has a significant and positive impact in promoting international collaboration research only in *Quantum Science*. However, Tukey post-hoc tests revealed that there is no significant difference in differentiating between governmental, defense-related, and corporate funding throughout all the paradigms ($p > .05$).

In order to check the national system differences, figure 4 brings the estimate of the random effects at country level. We can see that the US have a negative value for international collaboration, a pattern followed along the others technological paradigms. On the other hand, United Kingdom, Saudi Arabia, Spain and Belgium, for instance, are countries with high coefficients of international collaboration.

Therefore, we cannot confirm H1 whose the defense related research is less prone to promote international collaboration than other kinds of funding categories. Conversely, in the paradigm of *Quantum Science*, defense-related research has a positive impact, even though we could not differentiate this impact from the other kind of funding.

Table 5: International collaboration

	Nanotechnology	Quantum Science	Thin Films	Graphene
Frac_pub	-0.00 *	-0.00 *	-0.00 *	-0.00
	[-0.00, -0.00]	[-0.00, -0.00]	[-0.00, -0.00]	[-0.00, 0.00]
Defense	0.03	0.11 *	0.07	0.06
	[-0.05, 0.12]	[0.02, 0.21]	[-0.04, 0.18]	[-0.06, 0.18]
Government	0.06 ***	0.16 ***	0.09 ***	0.09 ***
	[0.03, 0.09]	[0.12, 0.20]	[0.05, 0.13]	[0.05, 0.14]
Corporation	0.06 **	0.17 ***	0.21 ***	0.14 ***
	[0.02, 0.10]	[0.12, 0.23]	[0.13, 0.30]	[0.07, 0.21]
N	2036	1395	1022	1097
N (country_refined:ag_refined)	231	159	117	125
N (country_refined)	53	41	37	32
AIC	-3184.49	-2233.36	-1705.60	-1660.42
BIC	-3133.92	-2186.19	-1661.24	-1615.42
R2 (fixed)	0.07	0.18	0.13	0.08
R2 (total)	0.65	0.74	0.76	0.74

*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$.

Confident intervals between brackets

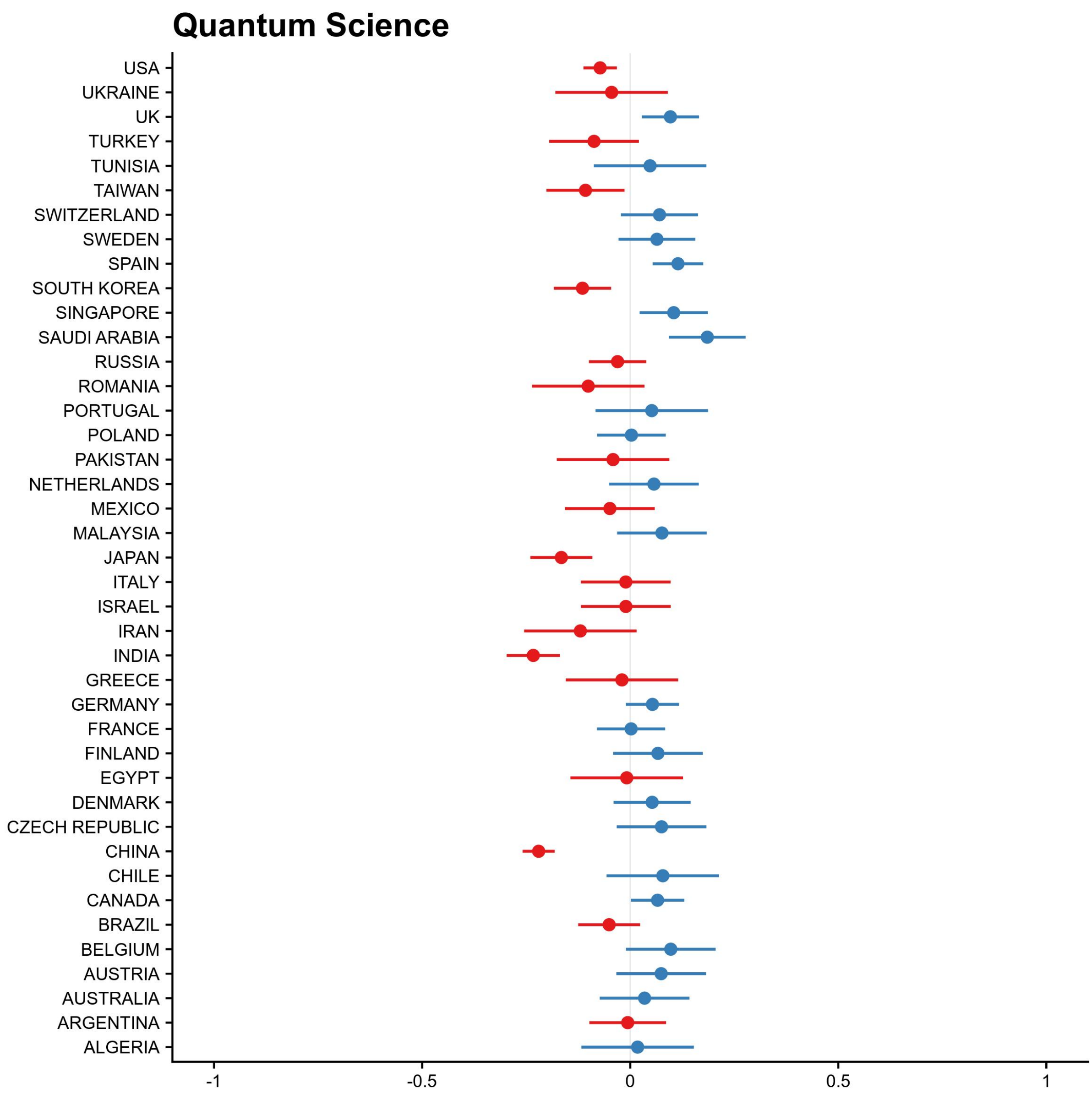

Figure 4: Random effects coefficients for international collaboration at country level

4.2 Short term impact

The factors representing the short term impact of the funding agencies, represented by the calculus of the FWCI, considered the citations received within 3 years from the paper publication, and as a function of the agency type and international collaboration are estimated in table 6.

The within indicator of international collaboration is significant and positive only in *Thin Films*, indicating that in this paradigm the funding agencies are becoming more internationally oriented. As a between effect, the international collaboration has a positive and significant effect in *Quantum Science* and *Thin Films*.

Concerning the funding categories, all of them have a significant and positive effect for the short term impact. The difference between the funding categories as estimated from Tukey post-hoc tests revealed significant differences between defense funding and governmental funding in *Quantum Science* ($p < .001$), *Thin Films* ($p < 0.1$), and *Graphene* ($ p <0.001)$. Comparing with corportation research, the difference is positive and significant in the same paradigms (*Quantum Science* $p < .01$; *Thin films* and *Graphene* $p < 0.1$).

Table 6: Short term impact

	Nanotechnology	Quantum Science	Thin Films	Graphene
Frac_pub	0.00	0.00	0.00	0.00
	[-0.00, 0.00]	[-0.00, 0.00]	[-0.00, 0.00]	[-0.00, 0.00]
Int_collaboration (Within)	-0.11	0.13	0.18	-0.22
	[-0.25, 0.03]	[-0.06, 0.33]	[-0.03, 0.39]	[-0.49, 0.05]
Int_collaboration (Between)	0.20	0.43 **	0.35 *	0.20
	[-0.03, 0.44]	[0.12, 0.73]	[0.06, 0.63]	[-0.25, 0.64]
Defense	0.31 ***	0.70 ***	0.37 ***	0.84 ***
	[0.15, 0.47]	[0.49, 0.91]	[0.19, 0.55]	[0.53, 1.16]
Government	0.16 ***	0.19 ***	0.14 ***	0.24 ***
	[0.09, 0.22]	[0.09, 0.28]	[0.07, 0.21]	[0.11, 0.37]
Corporation	0.28 ***	0.37 ***	0.28 **	0.35 **
	[0.20, 0.36]	[0.23, 0.52]	[0.11, 0.45]	[0.13, 0.56]
N	1242	863	637	625
N (country_refined:ag_refined)	213	148	108	106
N (country_refined)	48	41	37	29
AIC	2.07	135.11	-229.49	340.56
BIC	58.44	187.48	-180.47	389.37
R2 (fixed)	0.10	0.24	0.18	0.17
R2 (total)	0.56	0.67	0.64	0.62

*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$.

However, we need some cautions about this results, because as show in figure 5, the estimates about the defese-related research present wide confidence intervals. To explore the range of the impact, what may differ between the defense agencies, figure 5 brings the average FWCI over the period, considering the ten countries with higher funding intensity. Furthermore, we also bring information about Brazil and its funding agencies with the aim to understand in a general manner the role of funding in our national context.

We may note that in almost the countries presented, the no funding research acount for a FWCI below the national average. The Brazilian context follows the general trend with most of the funding agencies performing better that no funding research.

The defense-related agencies, in general, show a high impact performance. We may see that in *Graphene* and *Quantum Science* most of defense related research is higher than the national average and form a select group not only in national terms, but in the global landscape. In the other paradigms, the defense is still a high impact research category in the global arena, however, they are followed by other funding agencies at national level. Another important factor to highlight is the performance of China. This country has a considerable volume promoted by its funding agencies in all technological paradigms, however, their impact values are confined in a range between 0.5 to 1.5.

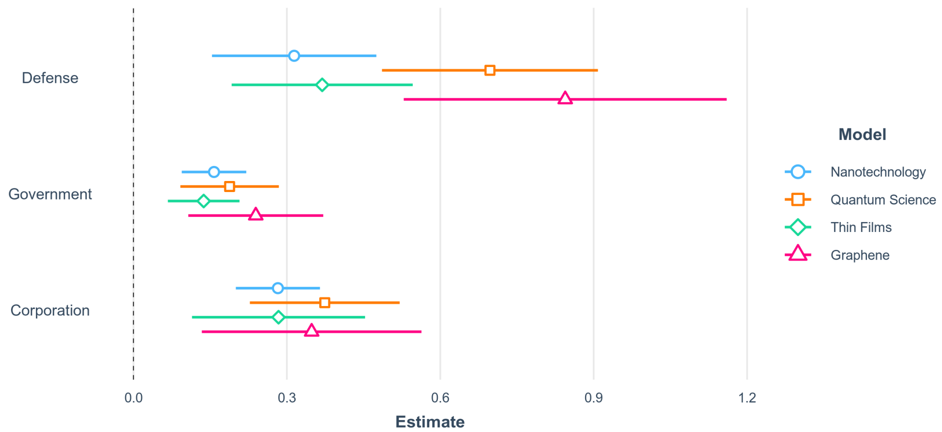

Figure 5: Confident intervals for models related to short term funding impact

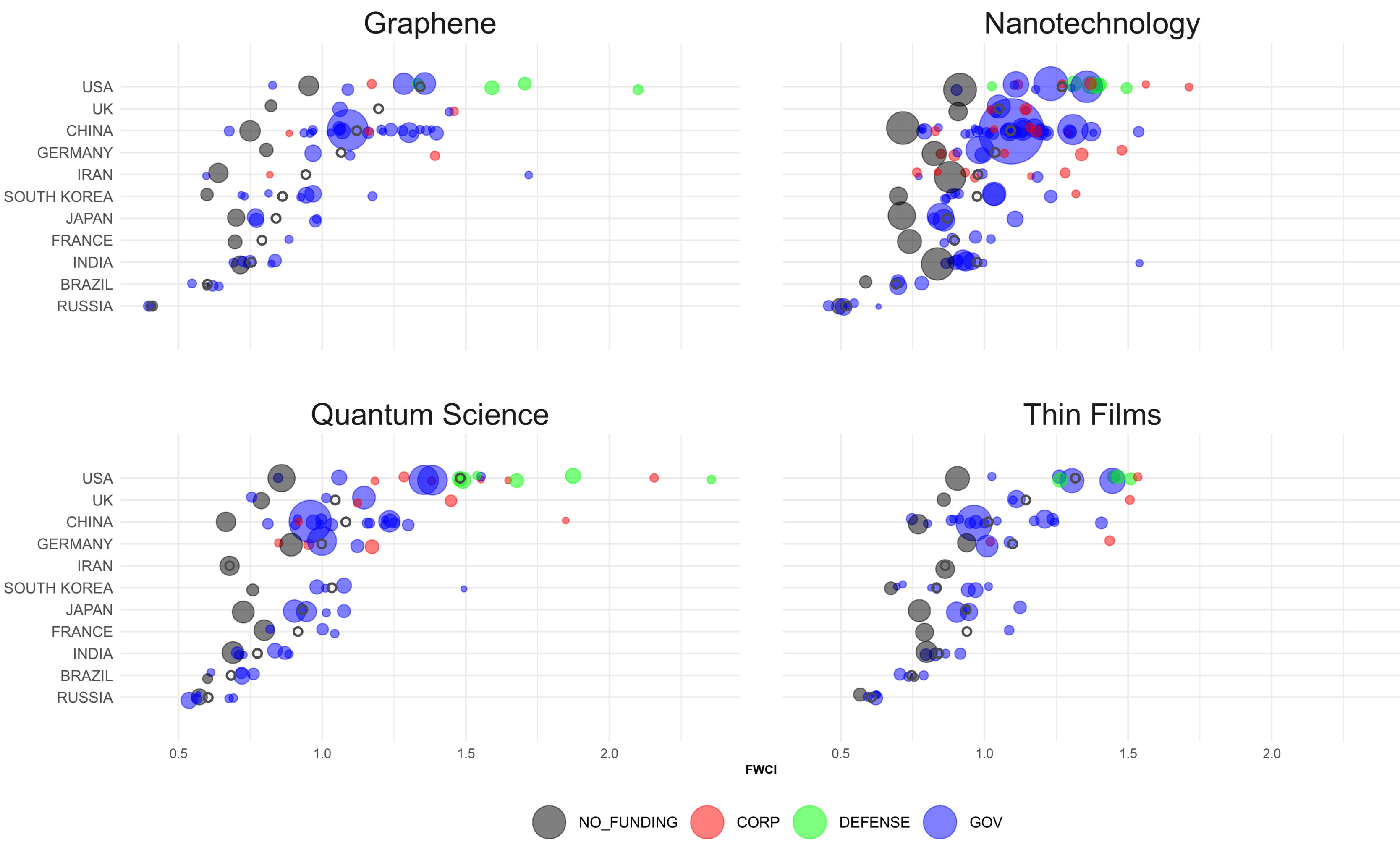

Figure 6: Average FWCI covering citations within 5 years by funding agency. Circles without colors represent the country average

4.3 Medium-term impact

The factors representing the short term impact of the funding agencies, represented by the calculus of the FWCI, considered the citations received within 5 years from the paper publication, and as a function of the agency type and international collaboration are estimated in table 7.

The within effect of international collaboration is negative and significant in Nanotechnology. Following the same pattern as we have shown in the short-term impact, the between effects of international collaboration is positive and significant in the *Quantum Science* and *Thin Films*.

Table 7: Midterm impact

	Nanotechnology	Quantum Science	Thin Films	Graphene
Frac_pub	0.00	0.00	0.00	0.00
	[-0.00, 0.00]	[-0.00, 0.00]	[-0.00, 0.00]	[-0.00, 0.00]
Int_collaboration (Within)	-0.67 ***	0.21	-0.12	-0.20
	[-0.89, -0.45]	[-0.12, 0.53]	[-0.46, 0.23]	[-0.67, 0.26]
Int_collaboration (Between)	0.11	0.55 **	0.37 *	0.39
	[-0.17, 0.39]	[0.19, 0.90]	[0.09, 0.64]	[-0.09, 0.86]
Defense	0.44 ***	0.75 ***	0.37 ***	0.94 ***
	[0.25, 0.62]	[0.51, 0.98]	[0.19, 0.56]	[0.65, 1.24]
Government	0.21 ***	0.15 **	0.16 ***	0.25 ***
	[0.13, 0.28]	[0.05, 0.26]	[0.08, 0.24]	[0.12, 0.38]
Corporation	0.26 ***	0.42 ***	0.33 ***	0.47 **
	[0.15, 0.37]	[0.24, 0.60]	[0.14, 0.52]	[0.20, 0.74]
N	675	511	379	332
N (country_refined:ag_refined)	171	128	95	83
N (country_refined)	46	39	33	27
AIC	-55.87	141.67	-52.60	213.27
BIC	-6.21	188.27	-9.29	255.12
R2 (fixed)	0.14	0.28	0.20	0.25
R2 (total)	0.67	0.69	0.63	0.64

*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$.

Concerning the funding categories, all of them have a significant and positive effect for the medium-term analysis. Tukey post-hoc tests show a positive and significant difference between defense-related research and governmental research in all technological paradigms with exception of *Thin films*. Likewise, the same pattern occurend when comparing the coefficients of defense-related with corporation funding. In this model, as before, we may check that the estimates of both defense-related research and corporation research showed wide confidence intervals (see figure 7). Therefore, it is important to check the specific agencies values in order to check the individual impact.

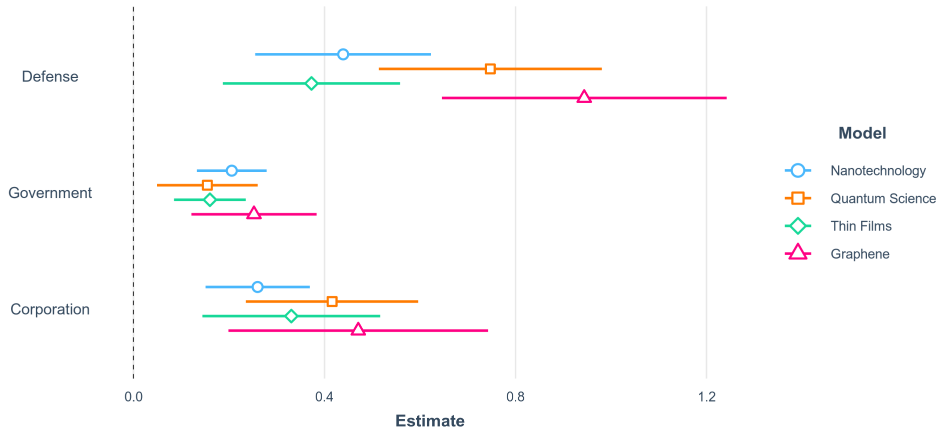

Figure 7: Confident intervals for models related to medium-term funding impact

Figure 8 brings the average FWCI over the period, considering the ten countries with higher funding intensity and Brazil. We may note that in almost all the countries presented the no funding research acount for a FWCI below the national average. Concerning the defense-related research, the pattern is similar to what occurred in the short-term impact. In general, the defense-related agencies show a high impact performance. We may see that in Graphene and Quantum Science most of defense related research is higher than the national average and form a select group not only in national terms, but also in the global landscape. In the other paradigms, the defense is still a high impact research category in the global arena, however, they are followed by other funding agencies at the national level.

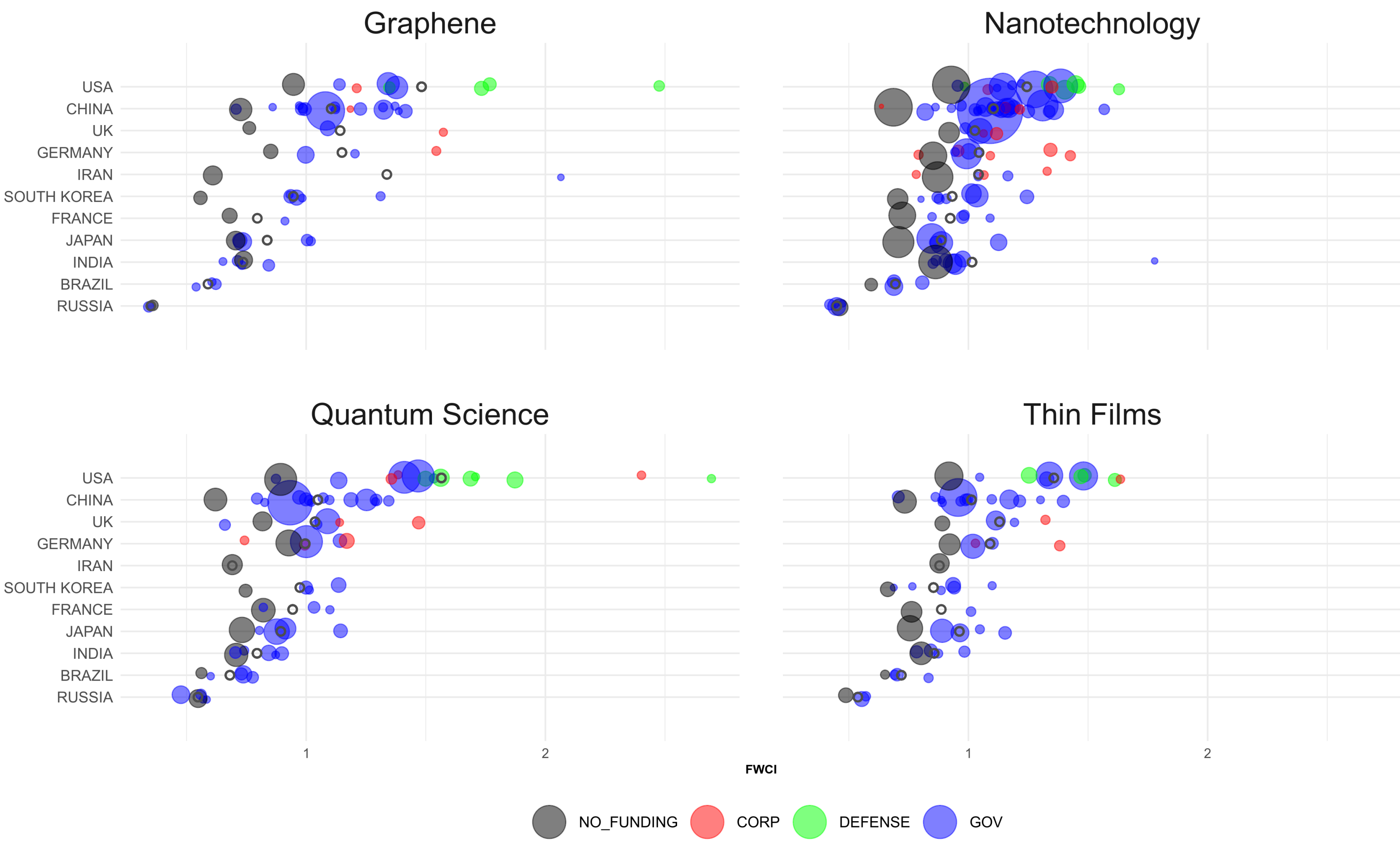

Figure 8: Average FWCI covering citations within 5 years by funding agency. Circles without colors represent the country average

4.4 Citation Flow

The *RQ4* is related to the source of knowledge where defense funded research get ideas and where it has impact. Figure 9 illustrates this process in the paradigm of quantum science and table 8 shows the flow indicators for each funding category separated by technological paradigm. The citation flow in the other paradigms are shown in the appendix.

Being the largest category of analysis, the governmental-funded research supplies most of the knowledge for each funding category in absolute terms. In all technological paradigms and in agreement with the results about the FWCI, both the defense-related and corporation funding have a proportion of citation higher than their proportion of published papers. For instance, in Quantum Science, while the defense accounts for 4.31% of the papers published, this funding stream accounts for 6.33% of the citations in the field. Additionally, most of the defense-funded published papers cites governmental funded research, a pattern which is consistent with all technological paradigms.

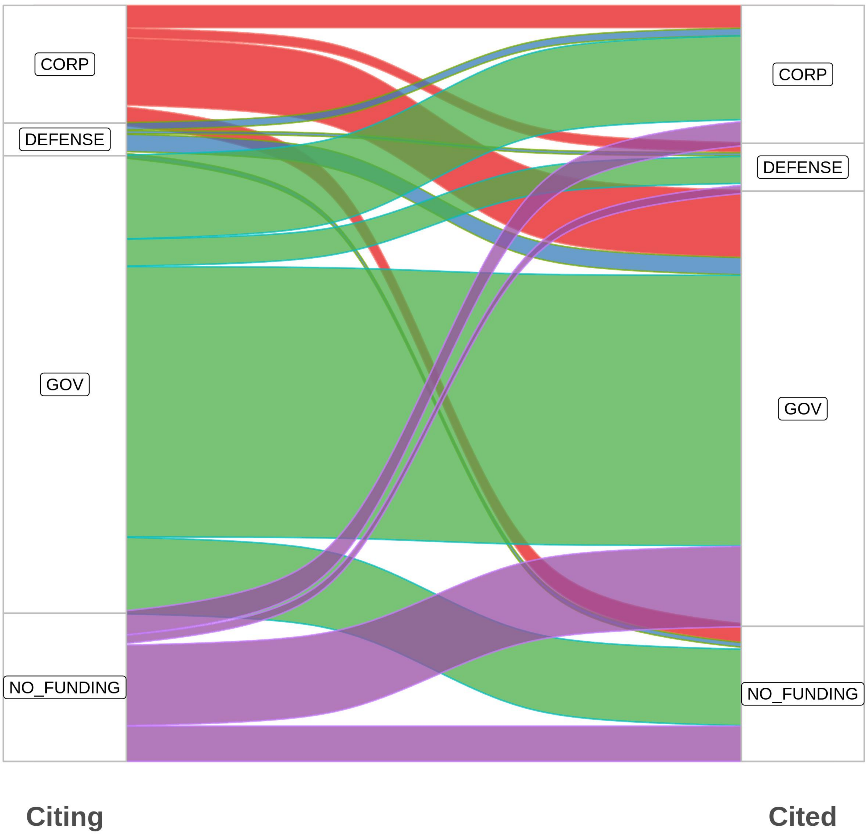

Figure 9: Knowledge exchange by funding type

Concerning the geographic source of citations, throughout all technological paradigms most of the citations come from funding agency of a different nationality. This phenomenon is exemplified by figure 10 which show the geographical flow dynamics in the field of *Quantum Science*. Given the high proportion of internationally funded cited papers, it is important to check for each funding category the ratio between international and national citations. The results are presented in the sixth column of table 8. In the case, throughout all the technological paradigms, the governmental funded researches usually cite proportionally more national sources than any other category. It is important to highlight that this geographical feature of the citation network is probably related to characteristic of the WoS dataset, where most of the articles are published in english.

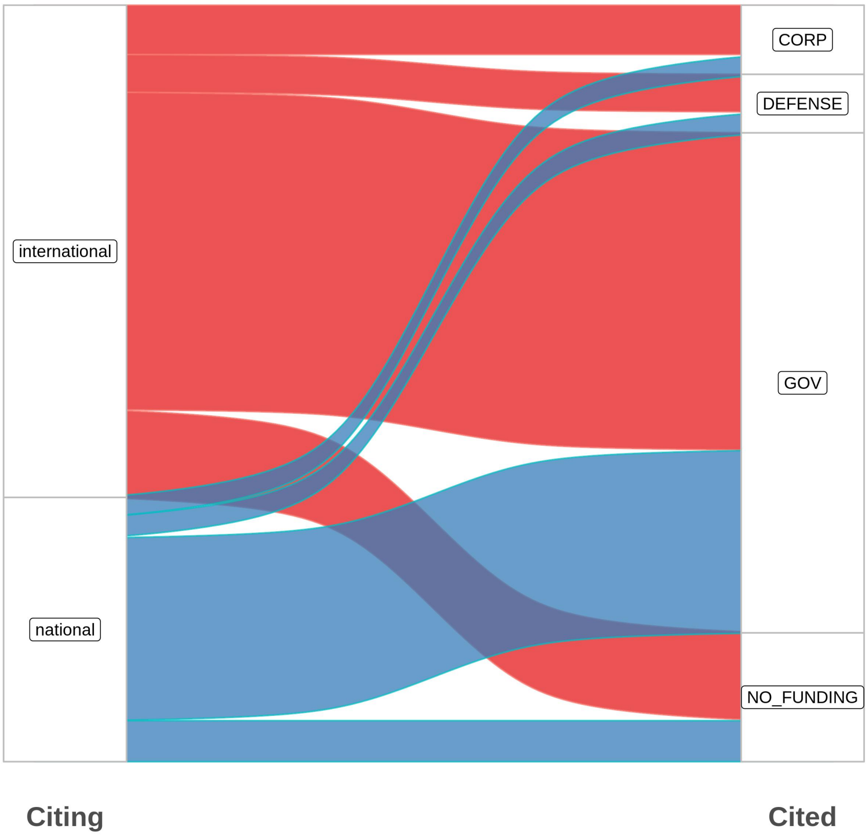

Figure 10: International Knowledge flow by funding type

4.5 Network position and reputation

The *RQ5* is related to the prestige of the defense-funded research, represented by the PageRank centrality in the citation network. In order to compare the performance of the funding agencies, we checked the difference between the rank position offered by the PageRank algorithm with the fractional counting rank. The results for each funding category, is presented in table 9. Concerning the average rank difference, we may can verify that the defense-related research presents only positive values, indicating that this group gains more than loses positions. Another group that shows positive values throughout all technological paradigms is the corporation funding, however, with average values below the defense-related research in all technological paradigms.

Table 8: Flow exchange between funding agencies

Tecnological Paradigm	category	%Publications	%Citations	Ratio %citations/ %publications	Ratio received citations (%international/ %national)
Nanotechnology	GOV	59.20	57.69	0.97	1.30
	NO_FUNDING	21.77	19.44	0.89	2.57
	CORP	16.58	19.09	1.15	2.33
	DEFENSE	2.45	3.78	1.55	2.35
Quantum Science	GOV	60.53	57.55	0.95	1.74
	NO_FUNDING	19.60	17.88	0.91	2.14
	CORP	15.56	18.23	1.17	2.50
	DEFENSE	4.31	6.33	1.47	1.81
Thin Films	GOV	60.36	58.73	0.97	1.47
	NO_FUNDING	23.68	21.28	0.90	1.89
	CORP	12.04	13.86	1.15	2.25
	DEFENSE	3.92	6.12	1.56	1.53
Graphene	GOV	62.65	60.42	0.96	1.33
	NO_FUNDING	18.33	15.90	0.87	2.53
	CORP	15.48	17.59	1.14	3.18
	DEFENSE	3.54	6.10	1.72	3.14

Table 9: Rank of the funding categories based on the citation network

names	Category	# Agencies	Average out-degree	Average rank difference
Nanotechnology	INTERNATIONAL	7	6,052.86 (11,132.35)	0.71 (30.59)
	GOV	234	4,577.35 (16,853.78)	-17.91 (76.18)
	DEFENSE	**8**	**4,456.62 (3,766.33)**	**14.62 (37.28)**
	NO_FUNDING	77	2,589.04 (4,409.9)	-13.7 (55.36)
	CORP	128	861.98 (1,345.92)	10.34 (57.24)
Quantum Science	INTERNATIONAL	7	5,455.43 (10,651.17)	15.29 (43.03)
	DEFENSE	**10**	**4,683 (4,717.88)**	**12.4 (24.23)**
	GOV	205	3,112.37 (8,451.18)	-18.59 (66.83)
	NO_FUNDING	71	1,579.89 (2,561.8)	-4.3 (46.62)
	CORP	96	882.88 (1,208.28)	8.82 (52.8)
Thin Films	INTERNATIONAL	7	2,426.14 (4,723.99)	7 (38.21)
	DEFENSE	**10**	**2,139 (2,328.72)**	**4.6 (26.74)**
	GOV	183	1,930.65 (5,502.35)	-16.89 (64.84)
	NO_FUNDING	60	1,455.03 (2,115.94)	-22.35 (41.21)
	CORP	83	428.99 (456.2)	6.47 (51.54)
Graphene	INTERNATIONAL	5	3,067.4 (4,964.47)	-3 (41.46)
	DEFENSE	**8**	**2,488.25 (2,399.52)**	**9.38 (18.62)**
	GOV	182	2,434.31 (8,413.46)	-20.9 (51.94)
	NO_FUNDING	49	1,099.2 (1,531.65)	-10.29 (43.55)
	CORP	81	513.58 (741.36)	7.11 (58.94)

[1] Comparison between PageRank centrality and out degree centrality in the citation network
[2] In parentheses is given the standard deviations
[3] The number of agencies in the no funding category represents the number of countries

To investigate the individual reputation of the defense-related research in a more detailed level of analysis, table 10 show the values of the 20 biggest agencies together with all the defense agencies in the paradigm of *Quantum Science*. In general, we can verify that most of the biggest organizations are Governmental. Only the United States and Germany account for no funding research amont the top-20 positions, and which presents a positive, however a low variation in ranking.

About the defense-related research, we may verify that the US Air Force and the US Army show a positive, however a low variation in ranking. The DARPA, the US NAVY, the US Department of Defense and the US National Security Agency, presented high and positive variation among the defense agencies, representing a group of medium-size and high reputation research agencies. Whereas, the Defense Threat Reduction Agency and the US Department of Homeland Security, at least in the *Quantum Science*, show negative values in the ranking difference and low volume of publications.

Another important factor to highlight is the presence of China between the biggest funding agencies. This country has four organizations among the top 10 funding agencies. However, with the exception of the National Natural Science Foundation of China which lost four positions in the PageRank (and still keeps a position among the top-5 organizations), the other Chinese funding agencies lost several positions.

Table 10: Rank of the funding agencies based on the citation network

Agency	Category	Fractional counting	Page Rank	Rank by size
NATIONAL NATURAL SCIENCE FOUNDATION CHINA	GOV	97,399	5	1 (-4)
NATIONAL SCIENCE FOUNDATION	GOV	38,759	1	2 (1)
US DEPARTMENT ENERGY	GOV	35,426	2	3 (1)
EUROPEAN COMISSION	INTERNATIONAL	29,493	3	4 (1)
NATIONAL BASIC RESEARCH PROGRAM CHINA	GOV	28,997	18	5 (-13)
GERMAN RESEARCH FOUNDATION	GOV	26,886	4	6 (2)
FUNDAMENTAL RESEARCH FUNDS CENTRAL UNIVERSITIES CHINA	GOV	15,808	63	7 (-56)
EPSRC UK	GOV	15,804	6	8 (2)
JAPANESE SOCIETY PROMOTION SCIENCE	GOV	15,398	11	9 (-2)
NO FUNDING_USA	NO_FUNDING	14,399	8	10 (2)
NATURAL SCIENCES ENGINEERING RESEARCH COUNCIL CANADA	GOV	14,028	7	11 (4)
MEXT	GOV	13,684	10	12 (2)
CNPQ	GOV	13,003	33	13 (-20)
US AIR FORCE	**DEFENSE**	**12,683**	**12**	**14 (2)**
CHINESE ACADEMY SCIENCE	GOV	11,146	41	15 (-26)
NATIONAL RESEARCH FOUNDATION KOREA	GOV	10,936	45	16 (-29)
MINISTRY EDUCATION SCIENCE TECHNOLOGY KOREA	GOV	10,805	42	17 (-25)
US ARMY	**DEFENSE**	**10,585**	**13**	**18 (5)**
NO FUNDING_GERMANY	NO_FUNDING	9,327	15	19 (4)
DARPA	**DEFENSE**	**9,022**	**9**	**20 (11)**
MINISTRY EDUCATION CHINA	GOV	8,084	112	21 (-91)
AUSTRALIAN RESEARCH COUNCIL	GOV	7,981	14	22 (8)
RUSSIAN FOUNDATION BASIC RESEARCH	GOV	7,947	52	23 (-29)
US NAVY	**DEFENSE**	**7,249**	**16**	**27 (11)**
IARPA	**DEFENSE**	**2,658**	**30**	**79 (49)**
US DEPARTMENT DEFENSE	**DEFENSE**	**1,824**	**65**	**104 (39)**
NATIONAL SECURITY AGENCY	**DEFENSE**	**987**	**115**	**154 (39)**
ODNI	**DEFENSE**	**962**	**150**	**158 (8)**
DEFENSE THREAT REDUCTION AGENCY	**DEFENSE**	**679**	**200**	**191 (-9)**
US DEPARTMENT HOMELAND SECURITY	**DEFENSE**	**181**	**339**	**308 (-31)**

[1] Comparison between PageRank centrality and out degree centrality in the citation network
[2] In parentheses is given the difference in ranking
[3] Funding Agencies ordered by the number of publications

5 Discussion and conclusion

The availability of funding data from WoS opens a new opportunity to understand the evolution of a sectoral system of innovation from bibliometric data. Thus, it is possible to identify technological paradigms and their evolution over time, as well as understand the mechanism of interaction and process of selection among the diverse actors that participate in the system. With this in mind, we presented a empirically grounded analysis of funding impact on the research promotion of the technological paradigms of *Nanotechnology*, *Quantum Science*, *Thin Films*, and *Graphene*.

Among the funding categories, we paid special attention to the performance of the defense-related research which comprises the set of the US National Security Agencies. Some of them, such as the US Army, the US Air Force, the US Navy and the DARPA, are incumbent organizations with a historical role in the development of groundbreaking technologies. Other organizations, such as the Intelligence Advanced Research Projects Agency (IARPA), and the Homeland Security Advanced Research Projects Agency (HSARPA), were created as a response to the 09/11 attacks with the specific role of R&D promotion in the areas of intelligence and homeland security respectively.

Based on the results presented before, this discussion section will treat about the following subjects: a) Funding impact and prestige, b) Informational power and research militarization, and c) Citation as representative of soft power influence.

5.1 Funding Impact and prestige

One general aspect of our analysis is the impact of funding categories on the promotion of technical research innovations in the technological paradigms of *Nanotechnology*, *Quantum Science*, *Thin Films*, and *Graphene*. Our results show that the presence of funding, represented by the funding acknowledgment declared in a paper, exerts a positive effect on the factors analyzed. Therefore, funding agencies in general promote research which mobilizes more international collaboration[4] and with high impact.

When analyzed the promotion of international collaboration, the effects of defense-related research are felt only in the paradigm of *Quantum Science*, with inconclusive results for the other technological paradigm. On the other hand, governmental and corporate/university funding has a positive impact on all technological paradigms.

Concerning the citation impact, the variables analyzed were the funding category and the international collaboration intensity of the funding agencies. The results about international collaboration showed differences from the two models. The between effects of international collaboration are more expressed in the short-term impact. However, this result should be analyzed more cautiously, since the medium-term impact covers a shorter period of analysis.

Concerning the funding impact, the results are consistent both for the short-term and medium-term impact, and the defense-related, and corporation/university research, figure as a selective category of high impact research. This is in part in line with the findings of Gök, Rigby and Shapira (2016, p. 724) which showed that “there is indeed a hierarchy of funding sources in terms of impact and this hierarchy is inversely related to their relative frequencies”. We said in part because among the defense-related researches, we have organizations responsible for a high scientific output that cannot be considered small size agencies, such as the US Army, US Navy and US Air Force. The IARPA, subordinated to the Director of National Intelligence, is the case of a small size and high impact agency.

Furthermore, even though the coefficient estimates of defense-related research are positive and significant in all technological paradigms, the qualitative analysis shown in figures 5 and 7, points to expressive impact in the paradigms of *Quantum Science* and *Graphene*, where the defense agencies show high performance both at the national and

[4]It is important to highlight that it is the case concerning me. I participated in a doctoral internship in the Rotterdam School of Management where part of this work was executed. This was possible only because of the funding from the Federal Police of Brazil

global level.

The semi-quantitative analysis about the citation network flow and the prestige of defense-related research, as measured by the PageRank, is in accordance with the previous results, where the defense-related agencies are positioned better than expected if we consider as the baseline their number of publications.

To conclude this section about research impact, it is important to point out the following about performance of the funding categories. The bulk of the research is promoted by governmental agencies. In this sense, to evaluate such organizations based only on the citation impact could be misleading. The continued promotion of scientific activities builds the knowledge base of a country in a determined field. This capacity would help not only the process of innovation, but also the activities of imitation. In a sense, since Cohen and Levinthal (1990) defined the term of *absorptive capacity* to express the organizational capacities to explore external knowledge, it is possible to say that at the more general level, the national level, government agencies are fostering national capabilities for international knowledge absorption either generating or replicating research at the national level, or inserting their scientists in international collaboration networks.

5.2 Informational Power and militarization of research

As we discussed in the section 2.1, one stream of literature brings the US defense-related research to the context of national security policy making. This line of reasoning fits the thought of List (2011), where the economic development would be a factor for promoting the nation's political power in the international relations. Thus, with a paraphrase of von Clausewitz (1984), Haslam (2006) sums up List's thoughts as the arena where the economy would be the continuation of the politics by other means.

With this analytical background in mind, some additional discussions must be raised about the processes of militarization of research. Thus, the US NSS is the most visible face since there is a set of military organizations which explicitly participate in the technological development, and consequently it is easier to separate the defense-related with an analysis based on the funding organizations. However, we could also consider a research militarization process from China (WALSH, 2011).

A interesting framework to understand the militarization of research and its impacts on society is to evaluate the results of this research in the line with typology of power.

Furthermore, as explained by Braman (2006), the information revolution created a new form of power, the informational power. This kind of power is exercised through the manipulation of the informational basis of the three traditional powers: a) instrumental power, b) structural power, and c) symbolic power.

The instrumental power is based on the use of resources of the material world via physical force. It is related with the use of military and police apparatus in order to force society behavior. The structural power is related to the manipulation of the social world by elaborating laws and institutions. Lastly, the symbolic power consists on shaping behavior through the manipulation of the material, social, and symbolic world by the use of linguistic symbols and/or images. As a result of the information revolution, Braman aggregate to the traditional typology the *informational power* which is exerted through the manipulation of the informational bases of the other forms of power, altering how they are exercised and changing their nature and effects. This new form or power is linked with the *informational states*, which "use control over information to produce and reproduce loci of power and to carve out areas of autonomous influence within the network environment" (BRAMAN, 2006, p. 36).

Therefore, there is a new kind of division between the countries and their governments and agencies that is based on unequal availability and access to strategic scientific information resources. In the same way, there is great difference among states concerning the ability to obtain these resources or the ability to produce them. As stated by Braman, the informational state knows more and more about the citizen while he or she knows less and less about the state. Thus, the state become “a probability.” In a similar way, the knowledge about the role of defense agencies and intelligence in directing technical paradigms are understudied, proven in the existence of few empirical studies, reaffirming the very evolution of the capitalist system, where there are no visibility of the interests of the hegemonic state, and consequentially, there is no visibility in its use of the informational power (BRITO, 2015, p. 381).

The technological development is relevant to and permeates each form of power. That could result in more complex and efficient weapons system that could keep the US technological leading in military issues (instrumental power). However, from a wider an social/civil perspective, the militarization of research needs a better consideration in future research concerning its effects on the structural power. In this sense, whilst the DARPA promoted the research that create the internet, the development of the quantum computer and quantum networks could alter and refresh the current information infrastructure with a new science-based technology. And as well as happened with the internet, the defense agencies are apparently leading this process.

Obviously, we are not defending a total non-involvement of the state in general, and the defense and security agencies in particular, in the promotion of technological development. However, in this interconnected world, the creation of networked systems which are in their origin linked to defense systems have to be analyzed cautiously for understanding their societal implications.

5.3 Citation as representative of soft power

The citation counting represent the impact of scientific research and helps to operationalize an objective comparison between organizations. However, this metric does not necessarily indicate the relevance of the scientific production. In a sense, the citation indicates the “herd effect” where some actors anticipate a path of research in a field and are followed by others. In the selected fields herein presented the United States lead the research with the participation of its defense agencies. This result indicates, besides the technological impact, one facet of the United States *soft power*. The term was coined by Nye (2012) to explain symbolic aspects of power. In a previous work, Nye (1990) had already delimited several national factors which generate influence for a country, such as the technological leadership.

Therefore, part of the performance difference between United States and China could be associated with the prevalence of the soft power former over the latter in the international arena. To illustrate this point, figure 11 shows the citation network of *Quantum Science*, where it is possible to visualize the network positions of the Chinese, US defense and governmental agencies. As explained in section 4.5, even though China has funding agencies with larger research output, their research prestige is below the expected. However, it is important to consider that the National Natural Science Foundation of China, the biggest Chinese funding agency, is among the top-5 organization in *Quantum Science*, below the US Department of Energy (considered a civil agency in this paper) but above all defense-related research.

To sum up, the Chinese agencies have low international collaboration intensity and low impact. In its turn, the US has also low international collaboration intensity but high impact, which could indicate the preponderance of soft power of the latter.

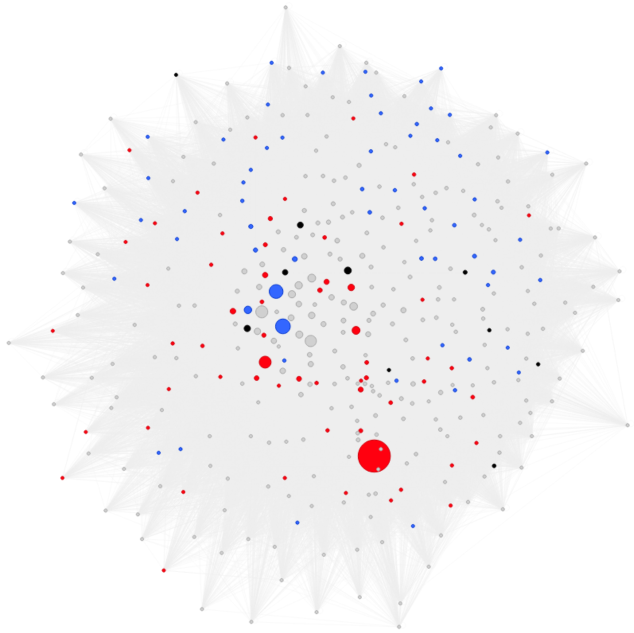

Figure 11: Citation network of Quantum Science. Blue are the US organizations, black the defense-related agencies, and red the Chinese organizations

5.4 Study limitations

Despite our meaningful findings about the technological content of the US NSS and its impact on the fields of *Nanotechnology*, *Quantum Science*, *Thin Films* and *Graphene*, this study is not without limitations. Since complete information about funding agencies is only available from 2009, this time range hindered the identification of longer-term changes inside technological paradigms. Furthermore, the funding information only denoted the presence of the funding agencies, without information about the amount of funding made available per paper. This hindered a more precise analysis of the evolution of the technological paradigms over time and their relative importance inside the system.

Additionally, our analysis is based on a low granularity both at the organizational and technological level. Some dynamics of sectoral system of innovation could be explained at fine-grained level. For instance, it would be important to consider the analysis of national laboratories and other organizations at lower hierarchical levels, once they may be different behaviors and performance results. Furthermore, the way that we analyzed the impact implies homogeneity along taxonomies. However, it would be possible that some specific taxonomies have greater importance in the paradigm development than others.

Besides that, the study is limited to only one dataset, offered by the Web of Science. Thus, additional studies should be done combining other datasets with global coverage, such as the Scopus, as well as datasets with national or regional scope. Furthermore, taking the results presented in Maciel, Bayerl and Kerr Pinheiro (2019), there are several areas where the impact of the defense-related research should be analyzed, such as Artificial Intelligence, Biotechnology, among others.

To conclude, based on the results herein presented, we cannot affirm that physical limits which impose constraints to the technological trajectory of the digital computer are close to or far way from being overcome, since the innovation process is cumulative and most of the time easy to detect only in hindsight. However, two points deserve considerations. Firstly, the US NSS is trying to overcome these physical limits, and secondly, in the specific technological trajectory of *Quantum Science* and *Graphene*, they are leading the fields.

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