IAC-14.E3.3.3

MEASURING COLLABORATION MECHANISMS IN THE CANADIAN SPACE SECTOR

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Innovation in space science and technology involves interactions among players from the public and private sectors. Inter-institutional and inter-sectoral collaborations have been proven to stimulate innovative activities and improve their outcomes in many activity sectors. The Government of Canada (GoC), including its designated agency for space-related affairs, the Canadian Space Agency (CSA), is one of the major players in the Canadian space sector and has played an important role in encouraging these collaborations. Consequently, Canadian government organizations emphasize the importance of inter-institutional collaboration in accelerating innovation, promoting spin-offs and ensuring sustainable funding for research and innovation programs. How should collaborations be measured, reported on and evaluated? Measuring the extent of collaboration is challenging due to the variety of collaboration mechanisms and the degree to which organizations report on their interactions. The space sector also has specificities that call for a distinct methodology: the culture of secrecy, publication practices, the competitive advantage of certain collaborations, the limited funding available, etc. This paper will present a methodology for studying collaborations in the Canadian space sector using bibliometric data, surveys, and publicly-available CSA contract data. Mapping these datasets will help identify the extent of inter-institutional collaborations, cross-fertilization between terrestrial and space research, and the

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impact of CSA funding on research outputs. Results from three case studies will be presented: Space Medicine and Life Sciences, Space Robotics and Rovers, and Earth Observation. Impact measurements not only play an important role in justifying stakeholders' investments, but also help clarify the innovation patterns and efficiency of the various mechanisms used.

INTRODUCTION

Innovation is no longer considered an isolated activity, and networks are becoming increasingly important in shaping and influencing the innovation ecosystem. Although technological developments in the commercialization of new products and processes is led by the private sector, the literature has shown that research conducted in the public sector (universities, government laboratories) has a positive impact on industry-developed innovation[1,2] and how inter-institutional collaborations work as a driver for innovation.[3–5] The government also plays a significant role in supporting innovation and encouraging collaborations.[6]

The space sector is similar in the potential impacts of industry-academia collaborations. The government's contribution is also of great importance to the space industry, especially when one considers market failure and monopsony (one principal buyer—the government).[7–9] Recently in Canada, the Aerospace review, also referred to as the Emerson report, was asked by the Government of Canada to assess the state of the Canadian space sector. Among its recommendations, the report underlined the importance of supporting collaboration between universities and industry to stimulate innovative activities and keep Canada at the forefront of innovation in the global space industry.[10]

How is the Canadian sector doing with collaborative activities to stimulate innovation? Success stories were outlined in the Emerson report, but a deeper investigation is required. Understanding the state of collaboration in a particular sector requires an analysis of multiple inputs and outputs, as partnerships take various forms. Measuring

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the performance of collaboration practices is thus a complex task calling for a hybrid approach. The following sections will describe the methodology and provide a partial picture of collaborative activities in the Canadian space sector; a first step in assessing the state of collaboration in Canada's space innovation ecosystem.

Measuring Collaboration

Collaborations between industry, academia and government in space innovation activities are difficult to assess thoroughly due to constraints in access to information and data. Inputs such as government and industrial funding and outputs such as scientific publications and patents only target certain forms of collaboration. There are multiple reasons for collaborating with other institutions, and a single method for measuring them is not sufficient.[11]

Various methods are available but, as stated earlier, no single one can provide a complete overview of collaboration mechanisms and practices. One method is bibliometrics and the use of co-authored publications. It has been identified by many scholars as a means of measuring scientific collaboration.[12–15] Publications are generally preferred by university researchers and, to a much lesser extent, by private companies, and therefore provide only one side of the story. Katz and Martin[16] outlined the fact that university–industry partnerships do not automatically lead to publication, even if the interactions contributed to new knowledge and technology. The result of such collaboration might be a patent or a simple technology transfer without any specific intellectual property protection apart from a non-disclosure agreement. Bibliometrics have to be handled cautiously when drawing conclusions. To evaluate the adequacy of measuring collaborations through co-publications, Lundberg et al.[11] compared co-publications with industrial funding data. They found very few overlaps when the two datasets (university-industry co-publishing and private research funding) were compared, and combining these two methods did not present the full picture. They suggest using additional survey data to better understand collaboration patterns.

Collaborations in the Canadian Space Sector

Methodology

The space sector covers a wide variety of activities and expertise, including biology, geology, and engineering. To obtain distinct collaboration patterns, three case studies were assessed: Earth Observation (specifically, publications related to Radarsat missions and applications), Space Medicine and Life Sciences, and Space Robotics. These case studies were chosen with knowledge of Canadian expertise, the actors' scientific contribution and the potential differences in collaboration mechanisms.

This study of the state of collaboration in the Canadian space sector consisted in four main phases. First, a bibliometric analysis was performed to evaluate publication trends (number of publications, types of collaboration, co-citations, keywords, impact factors). Secondly, co-publications and co-citations were translated into network graphs to visually demonstrate the link between the authors, the organizations and the publications' keywords. The third and fourth phases are still to be completed and consist in gathering information on funding (public and industrial funding of space innovation projects) and from surveys distributed to university researchers, employees of private companies, and government employees involved in space innovation. The survey will help understand the reasons for collaboration, the outputs of collaborative activities, the impact of CSA funding, and the perceived advantages and barriers to collaboration. The present paper will present the bibliometric findings and network analysis.

Data

The findings presented here use publication data from scientific journals and conference proceedings that were extracted from Scopus with a set of keywords tested by experts. The keywords aimed to be as inclusive as possible, while eliminating false positives. The full study includes more indicators, but those presented here are: the number of publications, co-authorships and co-publication networks. Data were collected from 2003 to 2012 and trends were analyzed between 2003–2007 and 2008–2012.

RESULTS

Bibliometric analysis showed that in the three case studies, Canada figures among the

top six countries in the number of articles published. As shown in *Table 1*, most were published by academic organizations, which is not surprising considering the importance of publication practices to university researchers.

TABLE 1 TO BE INSERTED HERE

The Radarsat case study shows that during the period from 2003 to 2007, the majority of published articles were written by government organizations, while an increase in academic authors is observed from 2008 to 2012. This can be explained by the importance of the government's role at the beginning of the Radarsat missions. Radarsat 1 was launched in 1995, and Radarsat 2 in 2007. The delay in making Radarsat capabilities available for scientific research is a possible reason for this observation. As mentioned, the government is an important player that figures large in publications for the other case studies, as well. When looking at single organizations and publication statistics for each case study, the government remains one of the most prolific publishers.

Given the lack of sustainable markets in Space Robotics and Space Medicine and Life Sciences, the Canadian Space Agency is a of major player. In the following paragraphs we will look at the organizations that published the most in each case study.

In the Space Medicine and Life Sciences case study between 2003 and 2007, at 16 articles, CSA had the greatest number of publications, followed by McGill University and the University of British Columbia with 14 and 9 articles, respectively. From 2008 to 2012, the CSA remained in first position with 29 publications, followed by the University of British Columbia and the University of Waterloo with 19 and 17 articles, respectively.

The Space Robotics case study differs from the others in its greater number of interactions with private industry. Although industry does not have a reputation for intensive publication practices, the conference proceedings included in this study (from the Scopus database) made it possible to include the private sector's publishing activities. From 2003 to 2007, CSA's 41 publications made it the organization with the most publications. In second place was the private firm MDA, with

39 articles. McGill University followed in third position with 10 articles. The period between 2008 and 2012 showed similar trends with CSA in first place with 28 publications, followed by MDA with 22 and the University of Toronto in third place with 21 publications. McGill University was in fourth place with 17 publications.

Government organizations remained dominant in Earth Observation data, but unlike the two other case studies, government organizations other than CSA also contributed. This seems to principally be due to the application of remote sensing data, which contributes to other sectors such as the environment, climate change, forestry and oceanography. The CSA certainly contributed greatly in the area of satellite technology, as evidenced by the 40 articles published by CSA authors between 2003 and 2007. CSA nevertheless published fewer than Natural Resources Canada (a government organization), which had 57 publications. MDA, the main contractor for Radarsat, occupied third position with 35 publications. Between 2008 and 2012, data users (*i.e.,* university researchers and government organizations such as Environment Canada, Natural Resources Canada, Fisheries and Oceans, etc.) produced more publications; CSA and MDA were no longer in the top five. With 70 articles, Natural Resources Canada had the greatest number of publications, followed by Agriculture and Agri-food Canada with 25 publications and Environment Canada with 24 publications. As the Earth Observation activity sector matured in Canada, the pool of users increased and more complementary products and applications were developed. The CSA succeeded in transferring the leadership of scientific work to other organizations to maximize the use of Radarsat data. CSA can thus be said to be fulfilling its mandate of supporting other government departments.

Types of collaboration

The co-publication data showed that a majority (between 50 and 60%) of collaborations occurred between the same types of institution; for example, one university collaborating with another. Few collaborations involved the triple helix concept, *i.e.,* partnerships between industry, university and government. *Table 2* shows the percentage of each type of collaboration in the three case studies.

TABLE 2 TO BE INSERTED HERE

The Radarsat study shows 55% of collaborations in silos; inter-institutional collaborations occurred mainly between universities and government. The previous observation on the roles of government and the private sector from 2003–2007 is reflected here again in collaborations between industry and government (13%).

The data from the Space Medicine and Life Sciences case study also show a majority of collaborations between universities. Private industry is not active in publishing in this field, but it seems that when collaborating, it tends to publish with both government and universities. One hypothesis is that the Government plays the role of intermediary between industry and academia in fostering collaborations. This case study also shows the highest percentage of publication without the collaboration of another institution; 17% in 2003–2007 and 11% in 2008–2012. Efforts are required to bring the players together in networks of expertise so connections leading to knowledge transfer and diffusion can be strengthened.

Finally, the Space Robotics activity sector is distinct from the other two case studies in the number of authors collaborating with universities. The private sector tends to collaborate most often with other companies and their publications are mainly conference proceedings. The Space Robotics sector is industry-driven and CSA contracts tend to be awarded to private companies, as the agency's robotics objectives focus on technology development. Collaborations are strategically handled by the private sector and are competitive advantages. This activity sector could benefit from more networking to establish more open collaboration habits and allow interactions with various actors in the ecosystem. Upcoming Canadian initiatives such as the Consortium for Aerospace Research and Innovation in Canada (CARIC) have the potential to support and increase partnerships.

Beyond a count of publications, networks were obtained from the co-publication data. These networks allowed the identification of a number of clusters (between 15 and 20), which demonstrated collaboration trends and the variety of connections. The networks

showed that although the presence of silos was high in each time period studied, the links between the clusters increased from 2003–2007 to 2008–2012. Co-authorships imply a level of cooperation and a flow and exchange of knowledge; the higher number of connections tends to indicate improved linkages among organizations. This increase in connections implies a higher level of knowledge diffusion.

Network position

Networks allow the identification of actors (individuals or organizations) occupying central positions who can act as intermediaries and facilitate knowledge transfer.[17] *Table 3* shows the three organizations with the most central positions in the network, based on the number of links they have with different organizations. The organizations with the most connections are not necessarily those with the greatest number of publications. In fact, some publications credit a wide variety of organizations, which increases the number of connections. This is the case for the majority of international collaborations.

TABLE 3 TO BE INSERTED HERE

Knowing the importance to space endeavours of international partnerships, and particularly the close relationship between CSA and NASA, it is not surprising that NASA holds a central position in the network of Canadian organizations for case studies in Space Medicine and Life Sciences and Space Robotics. In the Radarsat case study, the Canadian mission is more relevant to Canadian organizations, since NASA has its own remote sensing satellites. Although academic organizations are among the most active in publishing, only a few are central agents. This can be explained by university researchers' choice of collaborators; they tend to publish with a limited number of organizations and with the same partners on specific research topics, rather than participating in larger projects or missions.

National versus international collaborations

As mentioned earlier, due to the nature of space missions and the resources they require, space activities involve a number of international collaborations. Countries also try to distinguish themselves by acquiring a reputation and attaining leadership in certain technological and scientific fields. Early-stage work m therefore target regional and national

partners to build competencies in a niche area. Various patterns were observed in national and international organizations involved in scientific collaborations. *Table 4* shows the different trends in each of the case studies.

TABLE 4 TO BE INSERTED HERE

The co-publications using Earth Observation's Radarsat data mainly involve Canadian organizations, which account for 80% of collaborations in 2003–2007 and 66% in 2008–2012. One possible hypothesis for the decline is that once organizations gain experience with the data, they become more inclined to partner on other projects and expand their network to international collaborations.

Collaboration practices in the field of Space Medicine and Life Sciences are quite different, as the international component is much stronger; 41% of publications in 2003–2007 include at least one international partner, as do 50% for 2008–2012. When examining the articles included in this case study more closely, it is interesting to note how they apply to space missions and the International Space Station. This explains the high number of international collaborations.

Finally, Space Robotics is a Canadian niche, so, not surprisingly, it principally involves partnerships amongst Canadian organizations (75% for 2003–2007 and 70% for 2008–2012). Space Robotics appears to be a closed sector in Canada, where little international collaboration is shown in co-publication data. In the previous section, NASA appeared as a central player because of its connections with many other organizations. In the overall picture, NASA's role is much smaller. One interpretation is that most Canadian organizations collaborate with one another, but each individual organization will tend to collaborate with the same partner, limiting their network connectivity and impacting their centrality therein.

Analysis

If we now look at all data for each case study some interesting trends can be identified.

Earth Observation–Radarsat

The data from the bibliometric study showed that Canadian government organizations are important producers of scientific knowledge and important players in knowledge diffusion. They also hold a central position in the network due to their high number of connections with other organizations. Even though organizations tend to publish with collaborators from the same type of organization, inter-institutional collaborations also exist between universities and government, the two main users of Radarsat data. The role of CSA is also interesting, considering that their intense involvement in the first time period (2003–2007) was followed by a more secondary role in the second time period (2008–2012). The activity sector matured over the years and knowledge about the potential use of Radarsat data became more accessible to other organizations. This case study is a good example of how the CSA can contribute to the development of a technology and then stimulate scientific activities outside its walls. Finally, another interesting observation is the low level of collaboration between government-industry-universities: 4 from 2003–2007 and 0 from 2008–2012. This could certainly be improved to leverage all the benefits of government expertise, university knowledge and industry capabilities in support of future innovation.

Space Medicine and Life Science

This sector of activity depends mainly on government support, as there is no real market in Space Medicine and Life Sciences. This is shown in the datasets by the number of CSA authors' publications. CSA also plays a central role in connecting researchers. The connections with other Canadian and international organizations help promote an understanding of the production and diffusion dynamic of scientific knowledge in this field. The central role played by CSA and the international dimension both reflect the nature of Space Medicine and Life Sciences projects. These are usually linked to the International Space Station activities, led by international space agencies such as CSA. Finally, as publications focus principally on fundamental research and, to a lesser extent, on applied research, it is not surprising to note many publications by universities as well as intra-institutional collaborations. How can industry become more involved? It is worth mentioning that the Government, *i.e.,* the CSA, is also funding technology development

in Space Medicine and Life Sciences; the next five years may be critical in revealing if university-industry connections will lead to the production and diffusion of knowledge advancing the health, biomedical technology and life sciences fields. Involving more industrial partners to support CSA and space exploration objectives is definitely an interesting challenge for the Canadian Space Medicine and Life Science community.

Space Robotics

In the space industry, Space Robotics is known as an area of Canadian expertise. The Canadarm and Dextre legacy led to intensive technology development for rovers and the next Canadarm generation. In the past decade, substantial amounts of CSA money were dedicated to developing Space Robotics technology. In line with this, the data showed a higher private sector contribution as compared with the two other case studies. The lack of inter-institutional collaborations is also notable. This might be one element for improvement to foster industry-university collaboration and stimulate innovative activities. In addition, the low level of centrality of important industry players leads us to believe that these organizations maintain few links with other partners and tend to collaborate with the same ones. The competitive advantage of partnerships is certainly a consideration, but multiple collaborations at a low technology-readiness level (TRL) could be very successful. Players might not know each other well enough to fully exploit the potential of collaborations with diverse players. To better understand this, data from the upcoming survey will provide us with indications of the barriers, the reasons for collaboration and information on collaboration habits. It is possible that, although publications do not reflect it, industry may be collaborating intensively with universities without publishing the results.

Conclusion

This brief overview of three activities in which Canada's presence and reputation are very strong has shown three very distinct collaboration behaviors. The Earth Observation case study shows a transfer of dominance of the Radarsat technology to the end users. Space Robotics relies heavily on industrial expertise, while Space Medicine and Life Sciences are dominated by government interests.

Because our data focused on publications, the importance of collaboration with universities is significant. The space sector is nonetheless very much integrated, and collaboration with industry and government is commonplace—much more than other industrial sectors, where government is often not present or industry rarely contributes.

The co-publication data presented here are one way to look at collaborations, although they do not provide the full picture. The survey to be distributed shortly will investigate the collaborative habits of researchers and organizations. It will help establish trends and the reasons for collaboration. The comprehensiveness of the data collected will depend on the respondents' response rate. Another way of complementing bibliometric data is with funding data. As mentioned in the introduction, industrial and government funding may result in research partnerships that do not lead to publication. But since money does not always involve collaboration, the methodology of this study includes co-publication data and will be complemented with surveys and funding data.

Author Disclosure Statement

The authors received a grant from the Canadian Space Agency under the Capacity Building SS&T Cluster Pilots for a project in collaboration with HEC Montreal et ÉTS Montreal entitled M(IES)^{2}C: Measure of Impacts for the Economy and Society of the Investments in the Expertise in Space in Canada

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