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Viewpoint

An examination of non-linear and passive technology transfer in the space sector: Consideration of the Contingent Effectiveness Model as a basis for formal modeling

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ABSTRACT

Technology transfer has been a cornerstone of the justification for public expenditure of space technology development programs since at least the creation of NASA out of its predecessor agencies. Research into its mechanisms has, however, been largely qualitative and focused on actively managed, one-way transfer of technology from agencies to industry. In this paper we consider the effects of a wider range of mechanisms by which space agencies affect the technical knowledgebase, and examine the Contingent Effectiveness Model as a useful framework for formalizing comparative analysis of transfers.

1. Introduction

Technology transfer is a complex process that has been examined from sociological, economic, and political perspectives. In some cases researchers are concerned with the spread of technology across national lines, in others with the commercialization of university led research. In the world of space exploration and development, technology transfer is usually thought of synonymously with the concept of dual-use technology or spinoffs – technology originally developed for use in a mission by NASA, the US Department of Defense, or their counterparts in other nations which is then repurposed for application to more terrestrial problems.

Whether this characterization is accurate and appropriate to describe technology transfer and dissemination in the space sector, and how we might begin to develop formal models of these processes are the central questions investigated here. We first review and summarize the current state of technology transfer research in the space sector, as we consider criticism of the underlying assumptions that many researchers make in pursuing their investigations.

We then present the Contingent Effectiveness Model (CEM), originally developed to study transfers from university research to the private sector, as a possible basis for formal study of similar processes in the space sector, and consider three historical examples of transfers and contrast typical research methods for evaluating such cases with the methodology of the CEM.

Because the CEM depends on gathering data regarding conditions surrounding a transfer before that transfer has happened for fully rigorous analysis, we conclude not with any statement of which determinants or effectiveness criteria are most relevant to the space sector, but instead on the nature of the data which would be necessary to gather going forward so that future transfers might be evaluated more precisely and rigorously than previously.

Even for a high level framework such as the CEM, the key to successful modeling are a wide spectrum of data that can track not only actions surrounding a transfer of technology, but also the various environments within which the transfer has taken place. Such environments include, for example, organizational culture and health, legal, and regulatory.

2. Literature review

The Polish-American engineer and philosopher Alfred Korzybski coined the phrase, “the map is not the territory” to remind us that how we conceive of a thing, our model and description, is not the thing itself [1]. In considering technology transfer, it is very important to pay attention not to just what we fill in the map with,

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but where we draw its borders as well. What we do and do not consider as technology transfer will inevitably frame whom and what we consider the actors, motivations, and mechanisms of interest.

Aside from the popular "Spin-Off", researchers and policy-makers have used the terms technology adoption, adaption, acquisition, diffusion, commercialization, and valorization to describe technology transfer from the various points of view of their respective fields. This has caused some confusion and friction in the broader field. For example, the same set of events might be analyzed with financial and economic models by parties concerned with "technological commercialization", or with cultural and sociological models by those who see the same events as examples of "technological diffusion".

In the case of NASA and other space agencies, their status as public institutions often explicitly require some form of routine technological transfers to be conducted as a part of their mission. In NASA's case, this mandate extends back to the chartering of the organization with the National Aeronautics and Space Act of 1958. As such, the majority of research has been focused on precisely the type of transfers that are well suited to fulfilling NASA's mandate, as well as demonstrating the fulfillment of that mandate.

That is, the study of technology transfer is often narrowed in scope to focus on activities that are actively guided and managed, governed by contractual relationships, with a dedicated promoter, with a specific product that may be cited as a spin-off or dual-use technology.

NASA and other space agencies contribute to this focus not just by being the subject of study, but also by publishing a significant portion of the analyses. In the last twenty years, 20% of authors who have published work on technology transfer were employed directly by a space agency at the time of publication. The bulk of the remainder were academic researchers, with just two authors coming from the private sector [2].

In formulating their analyses, researchers have focused on six elements of a transfer:

1. Actors and sectors involved.
2. Specific technologies involved.
3. The paths employed.
4. Motivations for transfers.
5. Effectiveness of transfers.
6. Determinants (facilitating or impeding factors) of the transfer.

Metrics vary depending on the form of research. Surveys of involved parties, specific technologies transferred, or the paths by which the transfer takes place, are usually *ad hoc* and derived from case studies. In the last twenty years, 23 of 40 published papers were empirical evaluations, 16 of which were direct case studies [2].

Motivational and effectiveness metrics are closely tied, as it is often the expectation of impact that motivates the transfer in the first place. Economic and political metrics are often used. However, many authors are careful to point out that motivations and expectations for technology developers are distinct from those of the transferee, and still further for any involved intermediaries. They often focus on "Out-the-Door" evaluations, treating the implementation of a licensing contract or the transfer of a patent as the sole measure of success [3].

Developers and recipients often see the advantage of cost sharing and reduction, but will usually evaluate such things differently, as their alternatives and opportunity costs may share little to nothing in common. Recipients are usually primarily concerned with potential market impact and economic development, but these metrics may not inform an evaluation of the developer's motivation.

All of these considerations influence authors' perceptions of what were facilitating or impeding factors in the transfer process – the determinants – but they are usually grouped into one of three categories:

1. Institutional context of the transfer.
2. Characteristics of the technology itself.
3. Characteristics of the specific people involved.

Institutional context is the most universally recognized group of the three. Examples include the level of extant competition between firms in a sector or the prestige associated with it, availability of government or incubator funding, property rights regulation or legislation, or a number of other conditions that are distinguished by being independent of the technology and difficult or impossible to modify.

Although contextual determinants are difficult to quantify or generalize, they are not overly cumbersome to consider for two reasons. First, the most important effects of this class of determinants are usually easily measured by simpler metrics. The availability of outside funding obviously influences all concerned parties' cost evaluations, and property rights considerations usually influence risk-adjusted revenue expectations.

Second, because of the relatively small number of primary actors involved in space sector transfers, the range of possibilities that must be accounted for is narrower than in the broader technology transfer literature. As a result, performing comparative examination of data gathered from surveys need not account for as many possible conditions that may influence responses.

Technological determinants are often the easiest to identify, as they are likely to be cited by the recipient as the basis for their decision, regardless of whether it is accepted or rejected, and by the developer as well in the case of a successful transfer. The specific quality will naturally vary from technology to technology, but is usually related to improved performance, reduced cost, or a combination of the two.

Researchers have posited other technological determinants, but there are in some cases insufficient evidence for these, and in other cases apparent contradictions. For instance, Bach et al. [4] argue that technologies are in fact more likely to be transferred when less mature. However, Petroni et al. [5], and Zelkowitz [6] argue that at a very minimum, technologies are not viable for transfer before their behavior is known precisely, and that some transfers cannot take place at all before a technology is fully mature. Bach et al. [4], Petroni et al. [5] both agree that the technology must be generic enough to not require significant reworking for its adaptation to Earth use.

Personnel determinants are often the hardest to identify, but also frequently the most decisive. The level of familiarity with the technology possessed by the technical personnel at every institution involved with the transfer is important, but may be orthogonal to an individual's or an organization's interpersonal skills and their ability to communicate the necessary information to relevant parties. The attitudes and skills of senior management often come into effect. In some cases it was the direct interest of a CEO that promoted a specific transfer to a viable product rather than merely an acquired patent [6]. In others, overly bureaucratic processes or weak project management stymied otherwise promising transfers [4].

As stated previously, most papers are empirical, and of those the vast majority are case studies, and the complexity of the determinants issue begins to illuminate why. From Venturini and Verbano [2]:

"No analytical framework exists that is able to take into account