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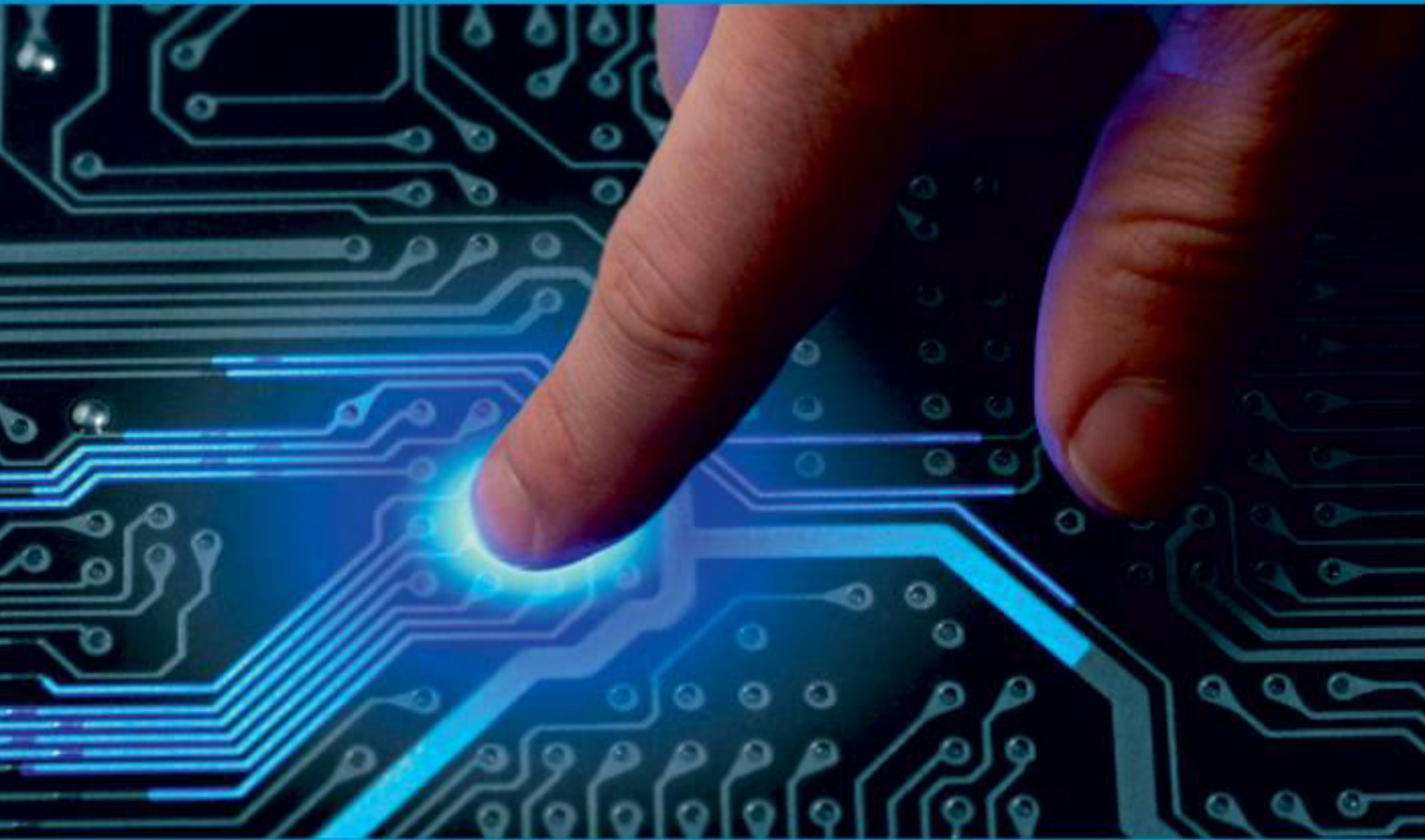

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Empirical Evidence from Biomedical Engineering Demonstrates the Various Mechanisms through which Information is transferred from Academia to Industry

Dr. S. Atheena Milagi Pandian, M. Rashika, N. Sri Manoj Kumar

Chief Executive Officer, Atheenapandian Organization, Courtallam, Chennai, Coimbatore, India

CTO & Vice President, Atheenapandian Organization, Courtallam, Chennai, Coimbatore, India

HEAD OPERATION OF BIOMEDOURSE, Atheenapandian Organization, Courtallam, Chennai, Coimbatore, India

ABSTRACT: The avenues for knowledge transfer between academia and industry are examined in this research. Our objective is to obtain an understanding of the relative frequency and perceived significance of various channels of knowledge transmission through a case study of the Biomedical Engineering faculty. The empirical data is based on a survey conducted among university professors, which is enhanced by in-person interviews. We develop a taxonomy of the knowledge transfer channels using factor and cluster analysis. Three categories of respondents are distinguished by the taxonomy, and we use regression analysis to connect the categories to the characteristics of the respondents. Our key discovery is that responders with a solid academic reputation and part-timers staff members who hold appointments in both industry and academia form unique categories of "knowledge transferors." The latter set of responders accepts traditional academic principles and strongly relies on traditional academic channels of knowledge transfer (academic papers, conferences), whereas part-timers heavily rely on personal networks. We derive several policy implications from our findings, including the fact that policies lacking a plurality of incentives and a broad range of channels are unlikely to be successful.

KEYWORDS*:* Academia Knowledge Transfer, Biomedical Engineering, Knowledge Infrastructure, Industry Science Relations.

I. INTRODUCTION

Science is playing a bigger role in achieving economic growth in contemporary knowledge economies (OECD 2002, Coriat and Weinstein 2001). The only way that structural economic growth is possible is if society's knowledge base grows and more productive methods of operation are developed. Universities have always been the home of science. But in order to play a significant role in the economy, new knowledge must inevitably be developed in universities and then disseminated to society more specifically, industry. There are significant variations in the ways that information is transferred between various nations and colleges (Polt et al. 2001). Policymakers can improve economic growth by optimising their knowledge transfer policies with the support of research that deepens understanding of the characteristics and effectiveness of knowledge transfer in various sectors, universities, countries, and regions. The debate surrounding the so-called "European Paradox" has brought attention to the significance of industry-scientist partnerships, or ISR, particularly in Europe. In comparison to its rivals, Europe leads the world in scientific research, according to the European Commission (1995). But over time, technological and commercial performance in high-tech industries has declined. Thus, the conversion of scientific discoveries into competitive benefits appears to be the primary weakness of the European knowledge economy. Increasing knowledge transfer from academia to industry is therefore considered to be one of the main goals of EU and member state policy. Our goal in this article is to shed light on the various avenues through which academics might transfer their knowledge from academia to industry. Ultimately, we chose to concentrate on a specific faculty (see below for the reasons we chose to do so). Specifically, we want to know how Industry Science Relations function within the Biomedical Engineering (BME) faculty. There are sub questions that can be derived from this primary research question: What is the relative frequency of usage for each of the many ISR forms used by the Biomedical Engineering faculty? What significance do the various ISR forms that the Biomedical Engineering faculty use have? Which variables affect the ISR pattern that the Biomedical Engineering

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faculty employs?

Currently, official relationships between universities and industry are the main topic of literature. Anecdotal data, however, suggests that informal relationships such as those formed at conferences, friendships, fairs, etc. also have a significant impact on ISR (Bongers et al. 2003). R&D managers serve as respondents in most research approaches used in the current literature. We employ the real "producers" of information that is, the researchers in our data gathering process, and we look into a wide range of formal and informal knowledge transmission techniques. The purpose of the next part is to provide a theoretical framework for our exploratory research by providing a quick overview of the current literature. The research methodology is covered in the third section. An overview of our empirical findings is then provided in the fourth part. The conclusions are covered in Section 5 along with some recommendations for policy.

II. LITERATURE

We give a quick overview of the literature in this part, concentrating on three main points. First, we inquire as to what aspects of knowledge are pertinent to an ISR study. Secondly, we present a comprehensive summary of potential ISR knowledge sharing techniques. Finally, we provide a quick overview of the variables that might affect a university researcher's usage of information transmission mechanisms.

2.1. KNOWLEDGE TYPES:

The goal of industry-science relations is to facilitate the sharing of knowledge between the involved parties. As a result, the type of knowledge being communicated in this research is crucial. Knowledge is multidimensional in nature. Three dimensions that have been prominent in the literature will be discussed. One can differentiate between explicit and tacit knowledge first. Explicit knowledge is transferable, even in the absence of human participants. Explicit knowledge can travel between academia and business in the form of books, scientific articles, patents, and other publications. However, humans are the embodiment of tacit knowledge, and they are necessary for its transfer. It is the kind of information that can only be acquired by genuine work experience and inquiry; texts or drawings cannot (yet) convey it. Explicit knowledge has not always existed in human history, but tacit knowledge has. Explicit knowledge, which has been employed by humans since the invention of writing, is actually a translation of tacit information. Informal knowledge can also be expressed as explicit knowledge, but knowledge can also flow the opposite way, from explicit to implicit (Nonaka and Takeuchi 1995). One could counter that not all implicit information translates into explicit knowledge. Heuristics used in searches are good instances of this. An expert operator of a complicated system, such as a chemical plant, will identify the root cause of the issue using a specific search heuristic. This search heuristic is very difficult, if not impossible, to transfer into explicit knowledge. The transfer of tacit knowledge is frequently regarded as a crucial component of knowledge transfer, even though the ICT revolution has increased the value of explicit information in several areas (David and Foray 1995). Research that is multidisciplinary as opposed to monodisciplinary can be recognised as a second dimension in characterising the nature of knowledge. Experts who work in disciplines have historically produced knowledge. However, at the cutting edge of knowledge production, the lines dividing these disciplines are frequently blurred, necessitating the synthesis of information from several disciplines in order to make progress. The field of aeronautical engineering is a prime illustration of this. An engineer working in this branch of technology must be knowledgeable in physics, mechanical engineering, material science, electrical engineering, aerodynamics, and other related fields. Scientific disciplines such as mathematics and electrotechnical engineering are examples of subjects that contain monodisciplinary knowledge.

The difference between the basic and applied forms of knowledge is the subject of a third and final classification scheme. It is possible to distinguish between basic, applied, and experimental research using the "Frascati manual" (OECD 1994). The goal of basic research is to learn more about the

environment we live in. The goal of applied research is to produce useful information that may be applied, for instance, to artefacts. Experimental knowledge can be considered the final category. The goal of experimental research is to determine if one variable affects another. If the differences between these three categories of research are interpreted too broadly, it could imply a linear theory of technological advancement that begins with basic research and progresses through applied and experimental work until the point of innovation.

Even while different kinds of research influence one another, it is evident that the time horizon at which research results may be used varies between industry and academia. ISR is instantly supported by the argument that private companies might not have enough incentive to conduct basic research (Nelson, 1959). However, there can also be "indirect"

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motivations for private companies to engage in fundamental research (Pavitt, 1993). For instance, fundamental research may provide researchers employed by businesses with a means of entry into the academic community, where they can acquire information and practical ideas, even in the event that it does not immediately yield financial rewards. Even while different kinds of research influence one another, it is evident that the time horizon at which research results may be used varies between industry and academia. ISR is instantly supported by the argument that private companies might not have enough incentive to conduct basic research (Nelson, 1959). However, there can also be "indirect" motivations for private companies to engage in fundamental research (Pavitt, 1993). For instance, fundamental research may provide researchers employed by businesses with an entry pass into the academic world, where they can acquire valuable information and ideas, even if it does not result in an immediate financial reward.

2.2. THE DYNAMICS OF SECTORAL KNOWLEDGE:

It has been proposed that an industry's knowledge base, which can be defined by the factors mentioned above, significantly influences industry dynamics. Nelson and Winter (1982), for instance, distinguished between two distinct "regimes" that an industry could fit within. First, there is an entrepreneurial regime in place where the entry of new, creative businesses occurs somewhat frequently. This is made feasible by the knowledge base's universal and non-cumulative nature, which is characteristic of knowledge bases based on science. High degrees of cumulativeness and specificity in the knowledge base lead to a "routinized" regime, which is characterised by innovation in well-established businesses. Malerba and Orsenigo (1996) also demonstrate how the sector's technological foundation affects patterns of inventive activity. A Schumpeter Mark I (widening) and a Schumpeter Mark II (deepening) regime are distinguished. According to the first, there is a high rate of new innovator entry, little consistency in the innovator ranking, and a modest economic size of innovators. Under the Schumpeter Mark II regime, innovators have low entry barriers, high levels of consistency in their ranking, and comparatively large economic sizes. The disparities in opportunity, appropriability, cumulativeness, and technology base qualities account for the various regimes.

Three distinct regimes were identified by Pavitt (1984): production-intensive enterprises, supplier-dominated organisations, and science-based firms2. These distinct paths arise from the knowledge base, client needs, and ways in which technological innovation might be safeguarded. Expanding upon Pavitt's (1984) taxonomy, Marsili (2001) has created a more comprehensive and scientifically supported classification. Science-based, fundamental process, complex systems, product engineering, and continuous process are the five regimes she separates. According to Marsili and Verspagen (2002), the physical and biological sciences frequently provide the knowledge foundation for the science-based system. High levels of technological opportunity, extensive R&D efforts, and close ties to academic research are characteristics of this system. Leading companies frequently exhibit a lack of variety in their knowledge base and approaches to innovative endeavours. Higher R&D, high knowledge and scale entrance barriers, and close ties to academic research are generally linked to increased opportunities for innovation. Low entry barriers to technology, however, might also exist with excellent chances for creativity. This can occur, among other places, in sectors of the economy where opportunities arise from the direct application of scientific discoveries made during university research to a wide range of products. Additionally, different industries use distinct knowledge transmission mechanisms. On the other hand, there is a difference between explicit and tacit information. According to Brunoni et al. (2005), the role of explicit information is the most significant in the scientific field. Such sectoral innovation system taxonomies (Malerba, 2005) suggest for innovation system replication (ISR) that each innovation system will prioritise a subset of various knowledge transfer channels. An innovation system based on science, for instance, would rely largely on scholarly articles. It goes without saying that additional theoretical and empirical research is required to connect sectoral innovation systems with knowledge transmission mechanisms. We are unable to accomplish this lofty goal in this work, but we will offer descriptive evidence of the significance of the various channels for the particular innovation field biomedical engineering that we explore.

2.3. CHANNELS FOR KNOWLEDGE TRANSAFER:

Knowledge is diverse and interacts with economic processes, creating multiple pathways for its transfer. Cohen et al. (2002) present an overview of the variety of ISR in the US. Bongers et al. (2003) offered a comparable but more detailed list of information transfer pathways, which we use here. Publication of research is perhaps one of the most archetypical methods of information sharing. Writing and sharing research results makes knowledge more accessible to a wider audience.

However, the nature of publishing allows only clear knowledge to be conveyed. Research suggests that relying solely on publications is insufficient for effectively implementing innovations. Furthermore, it might be claimed that using publications entails substantial transaction costs. To apply published knowledge, companies must invest in staff who

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can convert it into practical applications. In addition to publicising, academic scholars are often urged to attend conferences and seminars (B). It allows researchers to communicate directly with worldwide specialists. Speaking at conferences allows researchers to receive direct input from specialists, improving the quality of their work. Conferences and workshops can foster social networks among scientists in a specific topic. Mobility (C) is an essential source of knowledge transfer, despite its apparent simplicity. For a long time, mobility wasnot viewed as a method of knowledge transfer. Nonetheless, awareness of the importance of mobility is developing, and it is acknowledged that its impact has been underestimated (Bongers et al., 2003). Zucker et al. (1997) demonstrate the critical impact of star-scientist migration from university to industry. Mobility can also be beneficial for academic researchers who work part-time in industry. The production of grads or PhDs can also be significant. Extreme specialisation at universities might lead to difficulties for researchers due to lock-in effects. The expertise they have accumulated is difficult to convey, and few organisations truly require such (over-)specialized researchers as workers. Studies on mobility in the Netherlands yield varying results. According to OECD (2002), mobility in the Netherlands is high, although Bongers et al. (2003) believe it is relatively low. Many interactions between industry and universities appear to be informal (D). In the United Kingdom, just 10% of innovative enterprises have official relationships with universities, although over 50% see universities as a key source of innovation (OECD, 2002). Informal knowledge transfer commonly occurs through social networks. Education-related social networks, such as alumni societies, play a significant role in ISR. According to Bongers et al. (2003), personal networks are generally the first point of interaction between universities and industry.

Cooperation in R&D (E) is characterised by a shared articulation of research objectives and the establishment of long-term collaboration. Only a movement of money from industry to universities, as well as a flow of information in the opposite direction, is insufficient to constitute R&D cooperation. A long-term connection requires reciprocal advantages. An R&D project can also be embedded in individuals, such as a Ph.D. student. This Ph.D. student may draw additional forms of engagement, such as students graduating with the same subject. Cooperation can also take several forms. It may be claimed that large companies are more likely to engage in collaborative R&D. One example of co-employment is with a Ph.D. student. Research does not yield immediate profits. Second, larger organisations typically have greater financial resources to invest in R&D. To collaborate with a university, it's important to have a specific level of R&D to comprehend their research and provide valuable expertise or facilities. Some forms of collaboration require a minimum critical mass to be successful. Small enterprises, such as spin-offs, can also participate in cooperative research and development. Industry and universities can share knowledge by collaborating on education (G). Academia's principal business is education, which can also benefit industry employees. Another form of cooperation is the impact that industry has on the curriculum. This helps the university stay connected to the local economy and attract a skilled workforce.

Contract research and advice (H) is characterised by the industry asking queries of universities and paying for the answers. This results in a movement of information from academia to industry, as well as a flow of finance in the opposite direction. It may be claimed that the industry will only outsource research if it is not their primary business and can be done more cheaply elsewhere. Because of the disparities in incentive systems, some issues may develop while using these channels. The industry wants the solution to their inquiry to be exclusive to them, but academic researchers want their findings published. Intellectual property rights (IPRs) aim to promote innovation by monopolising and sharing new knowledge.

Universities may engage in intellectual property rights to ensure that research results benefit society. Some believe that most university research findings are not currently applicable. Developing a product from scientific research requires a considerable investment of money. Bekkers et al. (2003) suggest that corporations may not invest until they are confident that no one else will.

2.4. WITHIN-SECTOR VARIATION OF IPR:

Individual features in ISR play a significant role in determining the sources of variation within sectors. For example, reputation can influence how people interact. Researchers with a good reputation will be seen as more valuable by industrial partners. Proxies for reputation include patent filings, publications, scientific prizes, and university positions. A university researcher's position might influence their credibility and knowledge. For example, a professor may have greater knowledge than a Ph.D. student. Individual age may also impact ISR, as senior scientists typically have more contacts and information to contribute. Some types of knowledge are cumulative in nature, therefore scientists' knowledge bases continue to grow. The range of specialisation of a researcher will influence how knowledge is transferred. Researchers that do particularly specialised research will have a more difficult time translating their findings than researchers who conduct multidisciplinary study. Industrial R&D typically involves multiple disciplines, unlike academic research. The need to apply the study to an actual product (or service) will most likely necessitate far

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more interaction between disciplines than simply obtaining the 'evidence of the theory'. As a result, transdisciplinary academic research will be more aligned with industrial research, making it easier for industrial enterprises to absorb.

The primary drivers of organisations' R&D activity will be financial ones. The continuity and profitability of their business should be ensured by developing new items or improving their current one. Nevertheless, research needs to be put to use if it is to benefit industry. Applying academic research will make it easier for industry to adopt and more consistent with industry research. Moreover, one could contend that translating basic research into a good or service for process improvement will be more difficult and costly than translating applied research. A person's social network has an impact on the information they can access. According to social network theory, the best personal network for information transfer is one that is rich in "weak ties," or acquaintances (Granovetter, 1973). Individuals with a large number of friends interact with a wide range of social groupings, depending on the social networks of those acquaintances. Events like conferences, fairs, and alumni associations are common instances of how one could find weak ties.

III. METHODOLOGY

We conduct a case study of a single faculty at the Engineering colleges in order to investigate the range of knowledge transfer pathways. The Biomedical Engineering Faculty (BME) is the preferred faculty. Our
curiosity in the specific links between research staff members is the primary motivation for concentrating on this one faculty member, and we anticipate that this will be simple to find at a higher level of aggregation. The BME faculty is young and somewhat small. We expect this faculty to have a fairly well dispersed portfolio of industry relations, which is one of the reasons we chose it.

BME also involves the colleges of health sciences and medicine (located in Maastricht), mechanical engineering, applied physics, chemical engineering and chemistry, electrical engineering, mathematics, and computer science (all situated in Eindhoven). At both universities, research groups from Eindhoven and Maastricht collaborate and share resources. Part-time jobs are available for researchers from different faculties that work closely with BME at the faculty of BME. BME takes this action to guarantee that research maintains close linkages to the founding faculties. Part-time lecturers are appointed to improve interaction with industry. The faculty is divided into three divisions: Biomedical Imaging & Modelling (BIOMIM), Molecular Bioengineering & Molecular Imaging (MBEMI), and Biomechanics & Tissue Engineering (BMTE). These are then split down even further into seven departments. A set of questionnaires assessing attitudes, traits, and behaviour related to ISR was distributed to all BME researchers. The questionnaire's primary goal was to gauge how frequently and how important the various knowledge transmission channels were used. Staff employees at the selected faculty who conduct research (and so genuinely develop new knowledge) are our population. 85 of the 138 researchers who were contacted returned the questionnaire, representing a response rate of more than 62%. Only three of the seven research departments deviate more than 10% from the average, with the response rate varying somewhat throughout the departments. As a result, we do not weight the data and regard the collection of answers as a representative sample. We would classify BME as "science based industry," despite the fact that it is difficult to define in a single dimension. Since the electronics and chemical industries are the traditional core sectors of science-based enterprises, some of the activities at BME are typical instances of science-based firms. According to Pavitt (1984), public science as well as R&D and the production engineering department are the primary sources of knowledge for this industry. This is also demonstrated empirically in the biotechnology industry. High levels of knowledge transfer between public science and industry are almost always implied by the high importance of public science. According to McMillan et al. (2000), compared to other businesses, biotechnology depends significantly more on public research.

In a 1994 survey conducted in the life and health sciences sector, Campbell et al. (2005) discovered that more than 90% of the science enterprises that responded did have a connection to higher education. Universities are thought to be particularly significant in the field of biotechnology (Haug 1999, Audretsch et al. 1996, Zucker et al. 1998). The tools of appropriation in this industry will include patents, process secrecy, R&D know-how, and dynamic learning economies. Furthermore, they claim that innovative organisations are generally huge in size. Bio-engineering is one of the sectors where opportunities come from the direct application of scientific research, according to Marsili (2001). The fact that BME's knowledge base is multidisciplinary by nature is another feature of it. It is a synthesis of several faculties, and in order to produce a result, it must synthesise various types of information. Moreover, engineering is what the letter "E" in BME stands for. This suggests that there will be a reasonable application of the findings. It is to be assumed that industry favours both transdisciplinary and applied research. Transferring into a tangible product or

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service method will likely be less expensive than conducting interdisciplinary study. It is evident from the foregoing reasoning that BME will very certainly have close ties to industry.

IV. ANALYSIS

4.1. ANALYTICAL DESCRIPTION:

Our survey's key variable of interest is based on a question about the significance and frequency of use of 21 distinct knowledge transfer routes. A 5-point Likert scale is used to measure the dependent variables. For frequency of usage, it ranges from seldom or never used (1) to very often used (5), and for relative importance, it goes from extremely unimportant (1) to very important (5). "Neutral" refers to the middle group (3) in terms of both frequency and importance.

The first noteworthy finding is the strong correlation between the dimensions "relative importance" and "frequency." The mean scores of the 21 items have a correlation coefficient of 0.95 (0.92) for rank correlation. In actuality, people already carry out the information transfer activities they deem necessary. Furthermore, our results suggest that there is no reason (or opportunity) to differentiate between these two dimensions in practice, which is why the variable we will use below is the total of the two scores for each item.

The more conventional routes that scored highly were joint research and development projects, publications (particularly those that are refereed, i.e., academic publications), conferences and workshops. Surprisingly, "networks based on friendship" rank highly as well. Fairs, double bookings, and licences are at the bottom of the list. All things considered, nevertheless, there are not many disparities in the 21 items' means, particularly when it comes to the standard deviations.

V. CONCLUSION

In order to provide a comprehensive quantitative empirical picture of the pathways utilised in knowledge transfer between academia and business, this work builds on the research done by Bongers et al. (2003). We use this conceptual framework in a case study of the Biomedical Engineering faculty at the Netherlands' Eindhoven University of Technology. Our goals are to provide a basic taxonomy of industry science knowledge transfer that can be evaluated also for other examples, and to give an overview of the significance of the various channels in our particular case. Three distinct categories of researchers, each with a unique profile of knowledge transmission activities, make up the taxonomy we arrive at. Of these, two are particularly notable for their differences from the "base case." A researcher with a combined appointment in an industry and a university is the first of them. In contrast to the default example, this kind of researcher uses personal networks both official and informal to a very high degree. The "traditional scientist" is the second category of researchers. This kind of researcher relies primarily on conventional academic channels (academic papers, conferences) for knowledge transfer and has a respectable academic reputation.

The results may have several policy ramifications. The first is that information transfer is a multifaceted phenomena in fact. We can recognise numerous significant pathways and more than one kind of attitude towards knowledge transfer to industry, even in a case that is comparatively homogeneous. Therefore, a strategy that targets a variety of incentives and channels is probably going to be more successful than one that heavily relies on a single kind of reward. Furthermore, our findings indicate that scholars with a solid reputation might have a preference for more conventional means of disseminating knowledge. Additionally, many outlets (such as publishing and attending conferences) are rather passive and don't require the researchers that we questioned to do additional effort. It is possible that this indicates how difficult it is to persuade highly esteemed scientists—the "star scientists"—to use the "more involved" channels of knowledge transfer, which rely heavily on one's own personal networking efforts.

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