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TECHNOLOGY TRANSFER EVALUATION IN THE HIGH TECHNOLOGY INDUSTY: AN INTERDSCIPLINARY PERSPECTIVE

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The objective of this study is to suggest a novel approach to evaluate the potential for commercialisation of a new technology by developing a framework. More specifically, this study will examine the *'ex-ante'* evaluation of the technology transfer process, in this case where the final application falls in the asset management discipline. For this purpose, a case study focusing on a chosen technology stemming from the high technology sector will be used. The technology relates to the application of software for detection of weak signals which is an established method of signal processing in the field of astronomy. This technology has the potential to be used in areas other than astronomy with several possible applications in asset management such as detecting water leakage in pipes amongst others. The applicability to detect water leakage is chosen owing to several problems with detection in the industry as well as the impact it can have in saving water in the environment.

This study, therefore, will demonstrate the importance of interdisciplinary and cross-disciplinary technology transfer. The study will employ both technical and business evaluation methods including lab experiments and using the Delphi technique to address the research questions. In conclusion, the chosen technology's commercial potential will be tested through expert opinion thereby focusing on the impact of a new technology and the feasibility of alternate applications and potential future applications.

Key Words: Technology Transfer, Interdisciplinary, Evaluation

1 INTRODUCTION

Technology is an important aspect for the growth and development of an economy (Grosse, 1996). Technology comprises the ability to recognise technical problems, to develop new concepts as solutions and the ability to exploit the concepts in an effective way (Winter, 1988; Autio, 1991). Technology by itself does not provide the benefit, it is in-fact the applications of the technology which are important and it is the technology-transfer process which takes the technology from the laboratory and it is then developed to practical products and services (Gressani & Sonneborn, 1993; Spencer, 2001).

Technology Transfer (TT) is a highly expanding field of knowledge which is attracting a great deal of interest from institutions and industries alike (Reisman, 2005). Many firms choose to acquire new technologies and capabilities from other firms in different industries to maintain and enhance their competitiveness (Lord & Ranft, 2002). In fact, the ability of certain technologies to be applied in other disciplines opens the possibility of new and improved products and services. It is thus not surprising that there has been a significant increase in the research on technology transfer carried out to create and modify technology (Autio & Laamanen, 1995). Technology Transfer (TT) usually involves the participation of two parties, a transferor and a transferee but in a bigger picture it can involve companies, organisations (including institutions) or even an entire nation and there can be more than one discipline involved (Reisman, 2005). There are many documented examples of cross-disciplinary transfers, some which have been very successful. Take, for example, the case of a satellite developed to send images back to earth. The related technology in this case is Nuclear Magnetic Resonance (NMR) which is used to scan sections of the human body. This can be helpful in the diagnosis of cancer for example. The technology used by NASA to sharpen and enhance the images received from space was applied to the one used to scan the human body and this greatly helped in better diagnosis (Baker, 2000). An example from university to market is that of the University of Florida, which commercialised Gatorade, a sports drink developed by a professor which has earned the university about $94 million over the years from licensing alone (Dibella, 2005).

The above examples demonstrate that technologies can be used in areas other than those that they were originally intended for. As mentioned above, a similar approach is going to be taken in this research where a technology is going to be studied and a recommendation put forward as to how it should be commercialised for use in areas for which not originally intended.

Evaluation of technology transfer, whether it be before or after the transfer is evermore important in recent times. This is especially true for university related research as it is being recognised as an important source of innovation and economic development and this is verified by the fact that various industries are entering collaborations with universities and funding academic research (Rahal & Rabelo, 2006). "This dynamic involvement with industry has created new demands on the university to manage these activities so that the institution's primary goals of education, research, and dissemination of knowledge are not compromised but rather augmented, with conflicts minimized and managed"(COGR, 1999). This only goes to justify the need for a better evaluation tool that can be used to assess potential transfers from universities as well as other sources. Such a tool can be beneficial as it can aid in better decision making as well as selection of the right technology and subsequent selection of the most favourable mechanism for commercialisation.

The objective of this study is to develop a framework for evaluating the technology transfer process in the high technology sector and propose a suitable TT mechanism for commercialisation of an emerging high technology. More specifically this study will examine the *'ex-ante'* evaluation of the technology transfer process. As Harris and Harris (2004) stress there is no current framework to assess the likely success of the transfer of a technology before the product is designed, produced, marketed and put into use. In this context, the purpose of this study is to evaluate the technology transfer process with an interdisciplinary perspective. This study is different due to the fact that it combines the science and business disciplines and the evaluation methods will involve experiments as well methods used to collect data to contribute to the framework being proposed for the business aspect. According to Qin et al. (1997), the coming together of different disciplines can lead to the generation of new information and products. A research that spans beyond one discipline opens up more possibilities and allows for innovative ideas to be formulated and investigated. Interdisciplinary research is conducted to solve some questions that are complex owing to scientific curiosity or the society. This leads to researchers from different frontiers coming together to form a new discipline. Research is said to be interdisciplinary when there is more than just the bringing together of two or more disciplines. It involves the integration and co-ordination of ideas and methods (Committee on facilitating interdisciplinary research; committee on science, engineering, and public policy, 2004).

The evaluation of TT process has generated the greatest interest among technology transfer researchers, because it can determine the feasibility and value of the technology (Autio & Laamanen, 1995). Many studies have especially focused to evaluate the contribution of universities to the private sector in TT process (Carlsson & Stankiewicz, 1991; Saviotti, Bellon & Crow 1993). For example, Luik (2005) states that "Many of the researches arise from the need to evaluate the value of research carried out in research institutions". The purpose of this research, therefore, stems for the requirement of an '*ex-ante'* evaluation tool in an interdisciplinary field focusing on the high tech sector involving technologies in the area of astronomy with possible applications in medical or engineering amongst other areas. This is also supported by Roper et al's (2004) emphasis on proposing a framework for the '*ex-ante*' evaluation of publicly supported Research and Development (R & D) activities. For this purpose, a high technology from astronomy discipline will be selected. The technology relates to detection of weak signals through a set of correlators which is an established method of signal processing in the field of radio astronomy. With this method it is possible to differentiate weak signals from surrounding noise. This technology has the potential to be used in areas other than astronomy with several possible applications, for example, one possible application of interest would be to detect water leakage or tumours in the body. This study, therefore, will demonstrate the importance of interdisciplinary and cross-disciplinary technology transfer. The technology's commercial and market potential will be assessed along with the feasibility of transferring the technology.

The research questions below are identified as best being able to achieve the objectives of the research:

Research Question 1 (RQ1): What possible feasible applications will the technology in question have in other disciplines such as medicine or engineering?

Research Question 2 (RQ2): What important criteria should be involved in the *'ex-ante'* evaluation of the technology transfer process in high-tech industries?

Research Question 3 (RQ3): What is the effective mode of transfer to enable efficient commercialisation of the above technology and how to choose the most suitable path to commercialisation?

2 TECHNOLOGY TRANSFER

The technology transfer process plays an important role not only for universities but also for organisations and economic development as well (Dority, 2003). The term technology transfer has been defined in various ways in the literature. While a simplified definition by Pankova (2002) is "The diffusion of technology as well as the dispersion of know-how and skills", for the purpose of this study technology transfer can be defined as "the process by which technology, knowledge, and/or information developed in one organization, one area, or for one purpose is applied and utilized in another organization, in another area, or for other purpose" (Winebrake, 1992: 54). The nature of the technology itself is not the only factor that leads to successful technology transfer. There are other factors in the environment of the technology that play a part as well. Technology transfers can occur in various ways: licensing, direct foreign investments, technical agreements, joint ventures, turnkey projects and purchase of equipment amongst others (Wei, 1995).

In general, there are two main streams of research on technology transfer. The first stream of research looks at the barriers and facilitators to technology transfer. Kirkland (1999), for example, describes five groups of barriers:

- Legal barriers, mainly intellectual property rights
- Financial barriers, mainly a lack of financial resources
- Limited skilled manpower
- Communication barriers. These include the gap between scientists and people on the business side.
- Technological barriers and difficulties

Guilfoos (1989), on the other hand, classifies barriers to technology transfer into three main categories: technical, regulatory and people. Other researchers have also identified and classified barriers (see Greiner & Franza, 2003; Carr, 1992).

The second stream of research looks at models, mechanisms and frameworks of technology transfer. In this stream, technology transfer can be categorised as horizontal or vertical. Vertical transfer of technology moves through a discovery phase, a creative phase, a substantiate phase, a development and engineering phase which further leads to function and a technological system involving hardware, processes or a concept (Roman, 1970, p.129). Horizontal transfer occurs when technology from one place is transferred for application in another place, for example from one firm to another. Vertical transfer occurs when the process moves from basic to applied research or development and subsequently to commercialisation (Grosse, 1996).

3 EVALUATION THEORIES

The literature on evaluation of technologies and technology transfer covers a broad aspect of the assessment procedure. In general, evaluation can be defined as valuing the quality of an explicit methodology that can be scrutinised for its validity or simply the science of valuing (Scriven, 1981). In terms of technology evaluation, Harris and Harris (2004) maintain that technology tends to be evaluated in terms of its usability and functionality from an ergonomic perspective. However, when technology is transferred from one application to another, the wider context needs to be assessed. According to Jasinki (2006), evaluation of the transfer process includes, assessing the viability, gains, costs and risks of the technology. In the opinions of the OECD (1987) and Luik (2005), the important dimensions of evaluation include the scope of evaluation, the object of evaluation, the level of evaluation, the time span of evaluation, the purpose of evaluation, the criteria for evaluation and the organization, resources, and responsibility of evaluation. Some of the general categories of criteria identified in the literature encompass economic value, feasibility, measurement of indicators and potential for cross-fertilisation. Some of the methods used range from developing models and conducting surveys to micro and macro economic case studies and statistical and econometric analyses (OECD, 1987; Luik, 2005). Evaluation can usually occur at three different levels, namely '*ex-ante*' evaluation, interim evaluation and ex-post evaluation (Piric & Reeve, 1997). Miles et al. (2006) have portrayed this in figure 1.

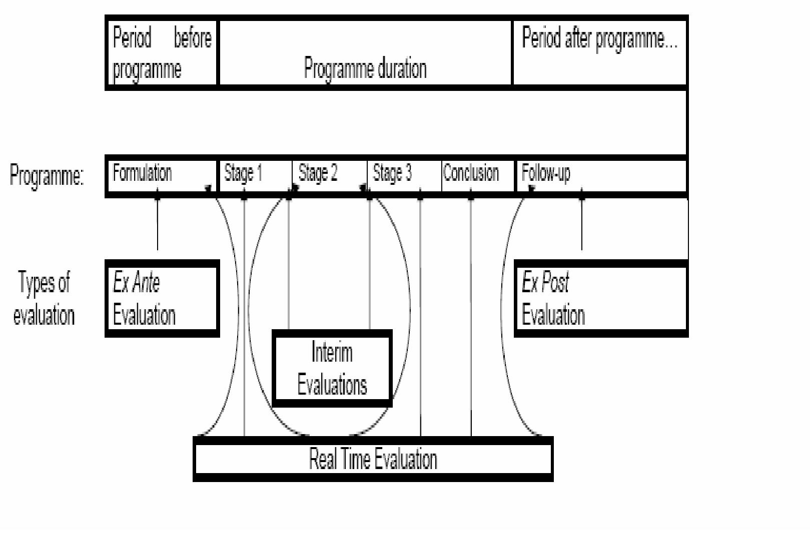

Figure 1: Levels of evaluation

4 THE TECHNOLOGY

In astronomy weak signals have to be detected. Radio signals from cosmic objects are difficult to detect as they are combined with a lot of noise. This is why there is a need for radio telescopes to have some sort of signal processor and one such example is that of a correlator. Correlators differentiate weak signals from surrounding noise. The signal of interest is said to be correlated and is amplified, whereas, the noise is uncorrelated and therefore, largely rejected. The receiving dishes are arranged in a certain fashion and referred to as a '*phased array'*. A phased array comprises of a group of antennas in which the relative phases of the respective signals feeding the antennas are varied in such a way that the effective radiation pattern of the array is reinforced in a desired direction and suppressed in undesired directions (Trinh et al., 1997) (see figure 2). These large dishes are used to concentrate the radio signals and the signals are combined using a correlator. These signals are weaker that those utilised for more general purposes like telecommunications.

Figure 2: Radio dishes at the Australia Telescope Compact Array (ATCA) at the Paul Wild observatory in Narrabri, NSW

The technology can be used in applications other than astronomy and one possible application of interest would be to detect water leakage in pipes for asset management purposes. This could be a particularly useful application owing to water shortage problems in Australia. Sound will arrive at the closer receiver first followed by a time delay and then received at further sensors. The time delay as well as other details such as the distance between the receivers and the velocity of sound in that environment will help pin-point the position of the leak. This will be tested and replicated on a small scale in a laboratory using four microphones in a line forming a phased array. Sound signals will be digitised and analysed using correlator software currently used in astronomy. This can be feasible because noise created from a leak will be different from background noise as well as the noise from normal water flow. Leaks can make different sounds and sometimes might go unnoticed and at other times are masked by background and surrounding sounds. The level of the sound of these leaks can be influenced by the amount of water and its pressure in the pipe, the physical nature of the pipe and location. Fortunately, the sound of the leak can sometimes be conducted along a pipe. The mechanism will involve pinpointing the location of the leak from the increasing intensity of the sound as it gets closer and closer to the device (SubSurface Leak Detection, Inc., 2006).

Once the basic proof of concept is tested, more components can be added to increase the accuracy of the device as well as make it user friendly. For example, connectivity to computers to log information, display of information on a screen, and power supply to make it portable. It might be possible to make the equipment water resistant so it could be used in humid environments. The idea is to see if this is possible and propose a feasible product while looking at all areas and then studying the whole process from origin to new product keeping in mind that the technology has moved from one area of application to a totally new one!

The technology chosen can have many possible applications, for example, in the security and medical fields for detecting growth of tumours by picking up sounds of the blood flow and tumour growth. For instance, there has been research on using acoustic methods to detect coronary heart disease non-invasively (Yasemin et al., 1993). For this thesis, only one application was chosen as it is to be studied in detail. The application related to water leakage was chosen owing to the water problems in Australia as explained previously. Like many of the examples stated there could be numerous applications but sometimes the most suitable one is chosen owing to many reasons such as availability of information. Another reason is the difficulty in detecting leak sounds accurately in plastic pipes as compared to a better success in metal ones. Furthermore, loss of water occurs in distribution systems frequently. A large percentage is lost while it flows through pipes from one point to another due to leakage which is generally the major cause amongst other causes such as public usage and theft. The amount of water lost can amount to 50 percent depending on the age and durability of the pipes. Furthermore, leaks can be caused by corrosion, installation issues, faults in the materials, pressure and in some cases ground movement due to drought, freezing and vibration from road traffic. This leads to loss of money and natural resources, especially, in Australia where there is severe water shortage, and therefore restrictions. Another problem is that leaks can give access to contaminants entering the water network, thereby, endangering public health (Hunaidi et al., 2000). The standard equipment used to locate leaks in pipes is acoustic devices. Leaks are detected by vibrations induced by leaks caused in the pipes. Position of leaks can also then be detected. Leak detections methods have been classified into three main categories, namely:

- Biological methods: using observation, odour or sound to locate leaks. This can be achieved by experienced manpower or trained dogs.

- Hardware methods: using devices to detect links. Devices such as acoustic sensors and infrared thermography are examples.

- Software methods: using software to detect leaks, for instance, by cross correlation (Tuner, 1991; Zhang, 1996).

The hardware based method is the most widely used method for leak detection amongst the three. One of the issues in using acoustic detection is that it is only efficient for metal pipes and not PVC as sound is not propagated very well in plastic. On the other hand, there is a possibility that leaks in both metal and plastic can be detected using non-acoustic methods but the fact of the matter is that these techniques are still limited in their utility and they are not as reputable as acoustic ones (Hunaidi et al., 2000).

5 METHODOLOGY

This section will briefly outline the methodology adapted to answer the research questions. The methodology will be divided into different phases, namely:

1.Phase 1: Technology assessment (R.Q. 1)

2.Phase 2: Business evaluation (R.Q. 2& 3)

Phase 1: Technology assessment (R.Q.1)

Experiments will be conducted at the QUT laboratories to determine the feasibility and applicability of the technology in question. According to Cavana et al (2001), lab experiments are those that are conducted in an artificial or contrived environment. Experiments are necessary as technical data needs to be screened.

Phase 2: Business evaluation (R.Q. 2 & 3)

The approach will involve a series of steps. Initially, the compilation of criteria from the literature which will result in a table of criteria. This will be followed by a refinement of these criteria using expert opinion by interviews followed by the rating of the chosen technology using the Delphi technique through interviews and questionnaires. Therefore, in this phase, the application of the above technology will be evaluated based on existing criteria from the literature along with some of the main mechanisms of transfer. It is first necessary to compile a refined list that can highlight the important criteria to be evaluated considering the opinion of the concerned experts. This will help in determining the best possible criteria and mechanism for transfer of the technology in question. To rate the aforementioned criteria, the Delphi method is well suited as it will help achieve convergence of expert opinion (Kaynak et al., 1994; Roest, 2002).

6 IMPLICATIONS AND FUTURE RESEARCH

Due to the fact that data collection is not complete results cannot be published yet. Figure 3 shows two acoustic signals from microphones arranged in a phase array. The preliminary results demonstrate that a distinctive sound can be picked up by the technology and this is the idea to be used for the detection of leaks.

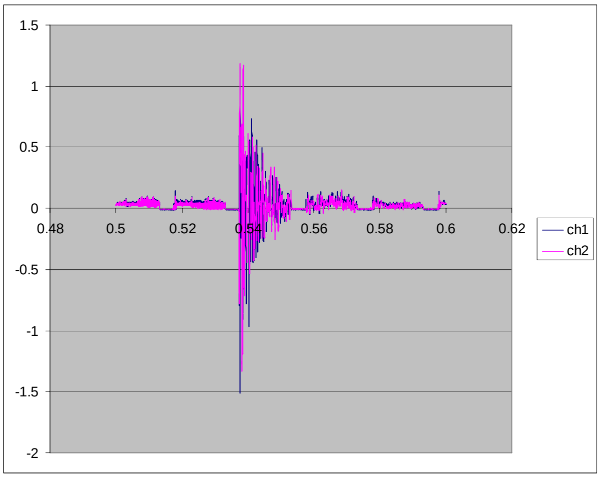

Figure 3: Preliminary results of the correlator software

The study will contribute to ongoing research on improving technology transfer models particularly in the above mentioned industry. A contribution that could be made is the identification of technical and business criteria and its incorporation into a framework for the *ex-ante* evaluation of the technology transfer process for the chosen technology which is part of the high tech sector along with suitable mechanisms to assist with the transfer. This will be achieved by consulting experts and getting the right opinion from them as well as relevant literature about the specific criteria and how they can help achieve successful transfer of the concerned technology. This will be useful because an in depth case study specific to a technology has been chosen and therefore it will address the concerned literature and add to the current knowledge in this area. Based on the technical and business evaluation a potential new application of the technology will be identified along with a commercialisation path. In this instance, the possibility of a new application for water leak detection and this is useful owing to the ongoing drought problems in Australia. Further research can involve investigating alternate applications of the technology as well further improvement through R & D to enhance the effectiveness of the application.

7 REFERENCES

1. Autio, E. (1991). 'What is Technology Transfer?' *Technology & Economy*, 24.
2. Autio, E. & Laamanen, T. (1995). Measurement and Evaluation of Technology Transfer: Review of Technology Transfer Mechanisms and Indicators, *International Journal of Technology Management, 10* (7/8).
3. Baker, D. (2000). *Scientific American: Inventions from Outer Space: Everyday Uses for NASA Technology.* Random House Reference.
4. Carlsson, B. & Stankiewicz, R. (1991). 'On the Nature, Function and Composition of Technological Systems'. *Journal of Evolutionary Economics, 1* (2), 93-118.
5. Carr, R.K. (1992). Doing Technology Transfer in Federal Laboratories, Part 1. *Journal of Technology Transfer, 17* (2: 3), 8 – 23.
6. Cavana.R.Y., Delahaye.B.L. & Sekaran.U. (2001). *Applied Business Research: Qualitative and Quantitative Methods*. Australia: John Wiley and Sons Australia, Ltd.
7. Committee on Facilitating Interdisciplinary Research; Committee on Science, Engineering, and Public Policy. (2004). *Facilitating Interdisciplinary Research.* Washington, D.C. The National Academic Press.
8. Council on Governmental Relations (COGR). (1999). *The Bayh- Dole Act: Guide to the Law and Implementing Regulations.* Washington D.C: COGR.
9. Dibella, S. (2005). Building Equity in Our Intellectual Property. *University of Nevada (Las Vegas) Magazine*
10. Dority, M. (2003). *Technology transfer and its role in the commercialisation process.A case study: The University of Missouri.* Office of Science and Technology,Missouri Department of Economic Development
11. Greiner, M.A. & Franza, R.M. (2003). Barriers and Bridges for Successful Environmental Technology Transfer. *Journal of Technology Transfer*, *28*, 167-177.
12. Gressani, C.A. & Sonneborn, M. (1993). Technology transfer: Marketing the future. *CNY Business Journal, 9* (11), 15.
13. Grosse, R. (1996). International technology transfer in services. *Journal of International Business Studies, 27* (4), 781 – 800.
14. Guilfoos, S.J. (1989). Bashing the Technology Insertion Barriers. *Air Force Journal of Logistics, 13* (1), 27-32.
15. Harris, D. & Harris, F.J. (2004). Evaluating the Transfer of Technology between Application Domains: A Critical Evaluation of the Human Component in the System. *Technology in Society*, *26* (4), 551 – 565.
16. Hunaidi, O., Chu, W., Wang, A. & Guan, W. (2000). Detecting Leaks Plastic Pipes. *AWWA, 92* (2), 82-94.
17. Jasinki, A, H. (2006). Barriers for Technology Transfer in Transition Economies: Results of Empirical Studies, Warsaw University.
18. Kaynak, E., Bloom, J., & Leibold, M. (1994). Using the Delphi Technique to Predict Future Tourism Potential. *Marketing Intelligence & Planning, 12* (7), 18-29.
19. Kirkland, J. (1999). *Introduction: Barriers to International Technology Transfer*. Dordrecht: Kluwer Academic Publishers.
20. Luik, A., (2005). Measurement and Evaluation of *Transnational Technology Transfer between R&D Institutions and SME-s.* Tallinn: Department of Product Development.
21. Miles, I., Cunningham, P., Cox, D., Crowe, C. & Malik, K. (2006). Smart Innovation: A Practical Guide to Evaluating Innovation Programmes; Supporting the Monitoring and Evaluation of Innovation Programmes. *A Study for DG Enterprise and Industry.*
22. Niosi, J., Saviotti, P., Bellon, B. & Crow, M. (1993). 'National Systems of Innovation: In Search of a Workable Concept'. *Technology in Society, 15*, 207-227.
23. Organisation for Economic Co-operation and Development (OECD). (1987). *Evaluation of Research: A selection of Current Practices, Organization for Economic Co-operation and Development.* Paris.
24. Organisation for Economic Co-operation and Development (OECD). (2001). *Knowledge-Based Industries.* Paris: Directorate for Science, Technology, and Industry/Economic Analysis Statistics
25. Pankova, L.(2002). Transfer of Space Technologies Past and Present: The Russian Case. *The Journal of Technology Transfer, 27* (4), 349-360.
26. Piric, A. & Reeve, N. (1997). Evaluation of Public Investment in R & D – Towards a Contingency Analysis (Chapter 5). *Policy Evaluation in Innovation and Technology: Towards Best Practices (Presentations at an OECD Conference held 26-27/06/1997).*
27. Qin, J., Lancaster, F.W. & Allen, B. (1997). Type and Levels of Collaboration in Interdisciplinary Research in the Sciences*. Journal of the American Society for Information Science*, *48* (10), 893-916.
28. Rahal, A.D. & Rabelo, L.C. (2006). Assessment Framework for the Evaluation and Prioritization of University Inventions for Licensing and Commercialization. *Engineering Management Journal, 18* (4).
29. Ranft, A.L. & Lord, M.D. (2002). Acquiring New Technologies and Capabilites: A Grounded Model of Acquisition Implementation. *Organization Science*, *13* (4).
30. Reisman, A. (2005). Transfer of Technologies: A Cross – Disciplinary Taxonomy. *Omega, 33* (3), 189 – 202.
31. Roest, I. (2002). *Expert Opinion: Use in Practice.* Amsterdam: Vrije Universiteit.

32. Roman, D.D. (1970). Technological forecasting in the Decision Process*. The Academy of Management Journal, 13* (2), 127-138.
33. Roper, S. Hewitt-Dundas, N. & Love, J.H. (2004). An Ex Ante Evaluation Framework for the Regional Benefits of Publicly Supported R&D projects. *Research Policy, 33* (3), 487-509.
34. Spencer, J.W. (2001). How Relevant is University –Based Scientific Research to Private High- Technology Firms? A United States – Japan Comparison. *Academy of Management Journal*, *44* (2), 432 – 440.
35. SubSurface Leak, Inc. (2006). *How to Find Leaks*. Retrieved February 17, 2007, from http://subsurfaceleak.com/find_leaks.html.
36. Trinh, P.D.,Yegnanarayanan, S., Coppinger, F. & Jalali, B. (1997). Silicon-on-Insulator (SOI) Phased-Array Wavelength Multi/Demultiplexer with Extremely Low-Polarization Sensitivity. *IEEE Photonics Technology Letters*, *9* (7).
37. Turner, N.C. (1991). *Hardware and Software Techniques for Pipeline Integrity and Leak Detection Monitoring.* Proceedings of Offshore Europe 91, Aberdeen, Scotland.
38. Wei, L. (1995). International Technology Transfer and Development of Technological Capabilities: A Theoretical Framework. *Technology in Society*, *17* (1), 103-120.
39. Winebrake, J. (1992).A Study of Technology-transfer Mechanisms for Federally Funded R&D. *Technology Transfer*, 54–61.
40. Winter, S.G. (1988). 'Knowledge and Competence as Strategic Assets', In: Teece, D. (eds) *The Competitive Challenge: Strategies for Industrial Innovation and Renewal.* U.S.A.
41. Yasemin, M.A., Metin, A., Walter, W., John, L.S. & John, B. K. (1993). Noninvasive Acoustical Detection of Coronary Artery Disease: A Comparative Study of Signal Processing Methods. *IEEE Transactions on Biomedical Engineering*, *40* (6).
42. Zhang, J. (1996). *Designing a Cost Effective and Reliable Pipeline Leak Detection System*. Pipeline Reliability Conference, Houston, TX, USA (November 19-22).

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