University of Alberta

The Effect of Multi/Interdisciplinary Research and Collaboration on the Technological Patent Value of Biofuel Patents

by

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Abstract

This exploratory study uses citation analysis to address: 1) the effect of multidisciplinary and interdisciplinary research on the technological patent values of biofuel patents, and 2) to determine the currency of the collaborative research that is being used. Both research objectives were addressed by analyzing the biofuel patents that were granted by the United States Patent and Trademark Office, between 1975 and 2002. Two key propositions were used to address each objective. The first proposition looked that the possibility of multidisciplinary and interdisciplinary research adding to technological patent value, while the second look a potential emphasis on the usage of cutting edge collaborative research. Both propositions were found not to be conclusively supported. Even though this research does not generate any conclusive results, it does provide insight into how multidisciplinary and interdisciplinary research is being used within the biofuels discipline.

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1. Introduction

As academic institutions continue to enter into the patenting process, there is an increasing shift in research methodologies from the traditional monodisciplinary approach to the more collaborative multidisciplinary[1] and interdisciplinary[2] approaches (Henderson et al., 1998; Thursby, J. and Thursby, M., 2002; Braun and Schubert, 2003). The shift in methodologies is being propagated in part by the emergence of innovative techno-scientific disciplines[3] such as biotechnology, bioengineering, and nanotechnology, which are either built upon or have emerged out of multidisciplinary and interdisciplinary research and collaboration (Lerner, 1994; Thursby, J. and Thursby, M., 2002; Sapsalis et al., 2006). Within these disciplines, multidisciplinary and interdisciplinary research is being integrated into degree programs, such as the Lakehead University biotechnology research program in Thunder Bay ON, localized research centers, such as the Centre for Prions and Protein Folding Diseases at the University of Alberta, Edmonton AB, and publications, such as Nature, and Science. Support for the promotion, and further utilization of multidisciplinary and interdisciplinary research is being generated in part by the social demand for effective methods for addressing the increasingly complex socio-scientific problems that current researchers are encountering (Mansfield and Lee, 1996; Mowery et al., 2001; Saragossi and van Pottelsberghe de la Potterie, 2003). The benefits that are associated with multidisciplinary and interdisciplinary research include: 1) increased opportunities for publication or patenting, 2) increased sources of funding, resources, and materials, 3) access to current or cutting edge research, and other researchers (Hicks, 1995), 4) knowledge

[1] Multidisciplinary: two or more researchers or research groups working in distinctly different disciplines, who work on segments of a common problem, and contribute to a single solution
[2] Interdisciplinary: researchers from distinctly different disciplines working as part of the same team or research group to solve a common problem. This particular form of collaboration requires a cognitive change in terms of a researchers world perspective, skills, and methodologies
[3] Techno-scientific discipline: a discipline that is strongly based in science, and oriented towards the production of technology and innovation

spillovers (Jaffe et al., 1993; Mansfield and Lee, 1996; Braun and Schubert, 2003), and 5) the validation of research, and individual prestige. Each of these listed benefits can be beneficial to everyone involved in the collaborative process.

To fully understand the benefits and effects of multidisciplinary and interdisciplinary research on scientific research, and technology development, the relationship between science and technology needs to be understood. The relationship between science and technology deals specifically with the transfer of knowledge between the two fields. Traditionally, monodisciplinary oriented research has been the dominate form of knowledge involved in this transfer. With the emergence of new scientific disciplines and changes in research practices, knowledge that is produced through collaborative research is becoming a more prominent part of the knowledge that is transferred between science and technology. The majority of the literature focuses on understanding the transfer between the two fields. Only a marginal portion of the available literature addresses the potential effect of changes in research practices and knowledge types on technology development or commercialization practices. Initial studies regarding the relationship between science and technology focused on gaining an understanding of the interaction between the two fields (de Salle Price, 1965; Narin and Noma, 1985; Narin et al., 1997; Van Looy et al., 2003). Later studies identified patents as being a physical link between science and technology (Collins and Wyatt, 1988; Narin et al., 1997; Meyer, 2000a). The identification of a physical link between the two fields enabled citation analysis, which was traditionally used for analyzing publications, to be applied to the patent literature. Citation analysis spurred the compilation of quantitative data that subsequently allowed for a broader range of research to be undertaken. Through the utilization of citation analysis scholars examined such topics as: 1) academic-industry collaboration (Meyer-Krahmer and Schmoch, 1998), 2) effect of commercialization activities on academic productivity (Geuna and Nesta, 2006; Meyer, 2006), 3) shifts in academic research practices (Thursby, J. and Thursby, M., 2002; Bruce et al., 2004), 4) the commercialization of academic research (Mansfield, 1998; Mowery and Ziedonis, 2002; Owen-Smith and Powell, 2003), 5) geographic knowledge spillovers (Jaffe et al., 1993; Mansfield and Lee, 1996), and 6) patent valuation (Trajtenberg, 1990; Lerner, 1994; Trajtenberg et al., 1997; Harhoff et al., 1999; Guellec and van Pottelsberghe de la Potterie, 2000; Gittelman and Kogut, 2003; Reitzig, 2003; Reitzig, 2004; Hall et al, 2005; Sapsalis et al., 2006).

The current review examines the emergence, role, and analysis of three main collaborative research methodologies: 1) monodisciplinary, 2) multidisciplinary, and 3) interdisciplinary. The review is composed of four sections. Section 2 reviews the literature on the relationship between the fields of science and technology. This section also reviews the use of citation analysis in quantitatively identifying, and measuring the links between science and technology. Section 3 addresses the literature regarding the theoretical framework and application of citation analysis. Section 4 reviews the role of academic-academic, and academic-industry collaboration in relation to collaborative research methods and citation analysis. Section 5 reviews the methods of patent valuation. Finally, Section 6 discusses the potential for future research.

2. Relationship between Science and Technology

2.1. Theoretical Background

The relationship between science and technology is prominently debated throughout the collaborative research and knowledge transfer literature. The debate itself is focused on the identification, and interpretation of the interactions and linkages between science and technology (Meyer, 2000b). Early studies generated linear models, which portrayed the fields of science and technology as being distinctly separate entities. These studies conceptually perceived science as being building blocks, the roots of a tree or as an unknown frontier (de Salle Price, 1965, p. 554). Technology in these early studies is metaphorically seen as being either the branches or the seeds of the tree. As a result, technology is perceived as stemming from or “growing out of scientific development” or as “giving birth to scientific interests” or motivations (de Salle Price, 1965, p. 554). In both scenarios science and technology are built upon the foundations for previous research. New scientific knowledge is built upon previous science, and new technology is built upon previous or established technology (Meyer, 2000b, p. 153). Within these models, knowledge flows linearly from science to technology. Science provides the knowledge base and the foundation that provides the means and support for technological development. As for scientific development it is driven by either previous knowledge, scientific research or by the catalyst of technology which generates new ideas.

de Salle Price (1965) was among the first to develop a linear model that symbolically represented the relationship of science and technology as a pair of dancers. During the dance each dancer is seen as being equal to the other, with neither one taking the lead. Within de Salle Price's model the exchange of knowledge and research is represented by the dance of the scientists and the technologists. The scientists are perceived as being responsible for producing and subsequently publishing basic research and public knowledge (de Salle Price, 1965, p. 563). The act of publication becomes the means of transference from the scientists to the technologists. Once the research is published, it becomes the responsibility or role of the technologists to utilize the research in the production of innovative technologies and processes. However, the transfer process is not instantaneous. A delay is generated by the time it takes for the technologist to access and utilize the published research.

Later studies perceive science and technology as being intermeshed and dependent upon each other, as opposed to the independent entities portrayed in earlier studies. Narin and Noma (1984) extend upon de Salle Price's (1965) dancer analogy by arguing that the integration of technology and science is so close that the two fields are becoming indistinguishable. Their study focused on the discipline of biotechnology to show that patents and publications are not distinctly different in the use of citations (Narin and Noma, 1984, p. 376). In conducting the study, the authors analyzed two citation elements found within biotechnology patents: 1) time distribution of references, and 2) the frequency of citations referring to top publications and patents. Their results indicated that there was a dependence of technology on science within the biotechnology discipline. Because biotechnology was an emerging discipline, the technological innovations that were being produced were highly dependent upon cutting-edge research. As a result, basic research was being transferred directly into technological development as soon as it was released from the research institutions (Narin and Noma, 1985, p. 377). Narin et al (1997) followed up the results of the Narin and Noma (1985) study and found again, over a decade later that science in the public domain was still the driving force behind innovative technologies.

Van Looy et al (2003) also found a positive correlation between the intensity of scientific research and technological productivity in the disciplines of biotechnology, pharmaceuticals, organic fine chemistry, and semiconductors. Accordingly, their results support the concept that basic scientific research strongly affects the technology development process. The increased production of basic research leads to the incorporation of more research into developed technologies, which in turn narrows the distance between science and technology (Van Looy et al., 2003, p. 358). The narrowing of gap between the two fields causes the interactions and transfers between science and technology become bidirectional. Science is the driving force that provides the research that is required to develop the technological innovation. The resulting revenue from the patenting of the technology provides economic support, and incentive to advance basic and applied research within the discipline.

Further studies recognized the duel function of patents (Trajtenberg et al., 1997; Meyer, 2000b; Reitzig, 2003). Studies by Meyer (2000b) and Reitzig (2003) indicate that the legal element of patents needs to be taken into account. As a legal document a patent's primary purpose and function is to control and protect the usage and transfer of technical knowledge. As a result a patent represents the establishment and definition of the property rights that were awarded at the time of the patent's granting (Trajtenberg et al., 1997, p. 21). Even though patents are internationally recognized as a form of legal protection there are still variations in the legal and social construction of these documents, which vary in correlation to national differences and boundaries (Meyer, 2000b, p. 159). As Meyer (2000b) has noted the legal and social construction of the patent document has caused the linkage between science and technology to become indirect. The indirect connection is created by the fact that the cited sources within the patent are more likely to indicate whether or not the technology is generated from an area that is perceived through publications as being scientifically relevant, but lacking in other technologies (Meyer, 2000b, p. 165). Therefore, citations are being utilized to ensure that the patent meets the two key requirements of novelty and usefulness. Reitzig (2003) incorporated the legal aspect of the patent document into his studies on economic patent valuation. Within the valuation process patents are seen as operating through the use of exclusionary rights, where only certain individuals or groups have complete access to the knowledge and technology. As result the patent document blocks any possible competitors for a set period of time, thereby limiting the supply of the innovation or technology, which can then potentially increase the patent's overall value. The larger a patent's geographic scope of protection, the fewer potential competitors there are, and the higher the patent's potential value is.

Due to the legal protection, property rights, royalties, and the generation of a competitive advantage through granted monopolies over patented technologies, patents can be seen as a beneficial or attractive investment. However, patents are accompanied by a number of negative attributes. One negative attribute involves the costs that are associated with a patent. The economic investment in a patent is fairly high and includes such expenses as legal fees, application costs, licensing fees, maintenance, and renewal costs. As Badar (2007, p. 123) points out the firms that are situated within technology oriented and driven disciplines are required to allocate increasing amounts of their research and development budgets to address these costs. As patenting costs rise, the amount of inventors or organizers who can afford to patents becomes smaller. For example, the amount of resources available to public or academic institutions is relatively limited, so as commercialization costs increase, the patenting of technologies becomes less of an option.

Another attribute is the increasing stringency of the patent requirements. Badar (2007, p. 122) notes that the production of research and technology has exponentially increased over time. Such an increase can potentially have two main affects on the patenting process. The first affect is seen through an increase in patent requirements, which may increase the waiting time for a patent to be granted. This particular factor is a negative attribute for disciplines and industries that feature rapid turnovers in the production of research and development. The second factor is increased threat of publication of similar knowledge prior to a patent's approval. With the increased availability of knowledge and research the potential exists for a competitor to independently develop a similar technology, and then opt to publish the findings instead of seeking patent protection. Provided the original inventor's patent has not been approved, then this publication of research would reduce the amount of research that can be protected by the patent. These are only two examples of the negative aspects that are associated with the patenting process.

2.2. Theoretical Approach

With the identification of the possible relationships between the fields of science and technology, came the necessity of finding a way to produce quantitative data for analysis. The method that is most commonly found throughout the literature for this type of analysis is citation analysis. Citation analysis is derived from the discipline of bibliometrics, which is the study of citation behavior in relation to scientific authors or academic journals (von Wartburg et al, 2005, p.1593). Citation analysis focuses specifically on the references that are cited within a publication or patent. Numerous studies, including Narin (1994), Mansfield and Lee (1996), Narin et al. (1997), Meyer (2000b), Thursby, J. and Thursby, M. (2002), and von Wartburg et al. (2005), have directly applied citation analysis to the patent literature for the specific purpose of understanding how basic scientific research is linked to innovative technologies. Other studies, such as Lerner (1994), Harhoff et al (1995), Sapsalis et al. (2006), and Mariani and Romanelli (2007), have utilized citation analysis to determine the value or impact of patents and scientific research.

Patents can be composed to two types of literature citations, patent citations and non-patent literature citations (Narin and Noma, 1985; Narin et al., 1997). Patents citations are references that are made to previous patents. These citations are typically utilized by the patent examiner as a method for establishing the area within which the technology is unique and innovative (Collins and Wyatt, 1988; Meyer, 2000a). Patent citations are representative of technical knowledge and the connections to other innovative technologies. Non-patent literature citations are composed of a variety of references which include: 1) academic sources, such as scientific journal articles, conference proceedings, and books, and 2) non-scientific sources, such as technical disclosures, industrial standards, engineering manuals, and any other type of publication (Narin et al., 1997, p. 318). Typically, non-patent literature citations are used by the patent applicant as a way of supporting the claims that are made about the innovation or technology. It is the non-patent literature within a patent that establishes the link between science and technology.

The quantitative application of citation analysis is extremely varied and includes: 1) patent valuation (Lerner, 1994; Harhoff et al., 1999; Guellec and van Pottelsberghe de la Potterie, 2000; Sapsalis et al., 2006), 2) determining changes in academic licensing practices (Mowery et al., 2001; Saragossi and van Pottelsberghe de la Potterie, 2003), 3) determining the impact of geographic location (Jaffe et al., 1993; Mansfield and Lee, 1996), and 4) determining the effect of different patent or researcher characteristics (Reitzig, 2003; Mariani and Romanelli, 2007). Within the patent literature there are two main types of citation analysis, forward and backward (von Wartburg et al., 2005, p. 1593). Forward citation analysis can be applied by compiling all of the patent and non-patent literature that cites a specific source patent. This form of analysis is used to provide an indication of the value, and potential impact of the patent or publication (Hall et al, 2005, p. 19). Examples of forward citation analysis can be found in: Trajtenberg (1990), Lerner (1994), Gittelman and Kogut (2003), von Wartburg et al (2005), Sapsalis et al. (2006), and Singh (2008). Due to a broad variation in the research scope and coverage of forward citation studies, the amount of information available on determining the value and impact of academic research on technology development is relatively limited.

Backward citation analysis operates in a similar fashion to the forward citation analysis with the exception that it compiles citation, and bibliographic information on all of the patent and non-patent literature that is cited within the source patent. This technique is used to examine the link between science and technology. Collins and Wyatt (1988) were among the first to apply this technique, which was commonly used in the analysis of publications, to the examination of patents. In their study, they were attempting to quantitatively understand the usefulness of basic research of various nations to the genetic disciplinary sector of the international scientific community (Collins and Wyatt, 1988, p. 72). The results Collins and Wyatt's (1988) study found that: 1) each of the studied countries studied was responsible for citing the majority of its own research, and 2) the citation methods traditionally used for publications worked equally well in application to patents.

As universities became more involved in commercialization activities, concerns over the shifting from basic research to applied research by faculty members was perceived as being a potential problem (Thursby, J. and Thursby, M., 2002, p. 91). Thursby, J. and Thursby, M. (2002) applied backward citation analysis to determine whether or not the increased patenting activity was generating the perceived shift in academic research practices. The findings of their study indicated that there was no significant shift from basic to applied research by scientific faculty members. The authors explained the increase in academic patenting as being generated by university administrators as a potential source of revenue (Thursby J. and Thursby, M., 2002, p. 102). Mariani and Romanelli (2007) combined the use of backward and forward citation analysis into a study on the correlation of the patent output of European industrial inventors and the inventor's characteristics, such as age, gender, and education level. The use of both forms of analysis allowed the authors to reduce the limitations found with the sole usage of forward citation analysis. These limitations include: 1) the underestimation in the number of citing patents, which is caused by the fact that only granted patents and published literature can be cited, 2) patent age, in the sense that older patents have had more of an opportunity to be cited, and 3) size and type of citing agents (Mariani and Romanelli, 2007, p. 1132).

3. Collaborative Research Methodologies and Approaches

3.1. Forms of Collaboration and Research

Research collaboration can be found in three primary forms: 1) monodisciplinary, 2) multidisciplinary, and 3) interdisciplinary. To understand how these approaches operate, the scope of a single discipline must first be understood. Within this review, a discipline is defined as being a self-contained community of experts who share a common methodology, experiences, and worldviews (Braun and Schubert, 2003, p. 183; Bruce et al., 2004, p. 458). Examples of a discipline include chemistry, anthropology, and mechanical engineering.

Monodisciplinary collaboration is the most familiar to and commonly used by academic and industry institutions. As the name implies all of the research, networking, and collaboration is confined to the research environment of a single discipline. The researchers who are trained or work in monodisciplinary research environments possess similar skills, theoretical outlooks, methods, and worldviews. Traditionally, the monodisciplinary approach has dominated the research environment. Since collaboration and networking are contained within the discipline, researchers encounter fewer communication barriers, and encounter problems with the transfer of knowledge.

Multidisciplinary collaboration involves two or more researchers or groups from distinctly different disciplines working with low levels of collaboration to solve individual segments of a larger problem (Bruce et al., 2004, p. 459). Multidisciplinary research differs from the interdisciplinary research by the fact that the collaboration that occurs does not affect either the academic communities or the worldviews of the researchers involved in the process (Bruce et al., 2004, p. 459). Multidisciplinary collaboration is often utilized in situations where researchers or research teams can work side by side on a set of distinct aspects that are contained within the framework of a larger inclusive research or a socio-scientific problem (Braun and Schubert, 2003; Bruce et al., 2004).

Interdisciplinary research involves the direct collaboration of two or more researchers or groups from distinctly different disciplines, which results in the generation of new or innovative knowledge that could not be produced by a single discipline (Bruan and Schubert, 2003, p. 460). The generation of such innovative knowledge requires changes to be made to by the academic researchers, and to the communication structures and/or networks. These type of changes breakdown the existing barriers between disciplines that are generated by differences in methodologies, terminologies, and worldviews, to allow for increases in collaboration and networking. Examples of interdisciplinary disciplines include biochemistry, bioengineering, and mathematical biology, all of which were formed through the collaboration of biology with various other disciplines.

3.2. Collaborative Research Methodologies

As new techno-scientific disciplines such as nanotechnology, emerge there appears to be a shift away from the traditional monodisciplinary forms of collaboration (Lerner, 1994; Thursby, J. and Thursby, M., 2002; Sapsalis et al., 2006). Researchers within these emerging disciplines are being confronted with a combination of increasingly complex socio-scientific problems, and limitations in acquiring all of the necessary skills, resources, and funds needed for scientific research (Hicks and Katz, 1996). According to Bruce et al (2004), the demands and problems surrounding the lack of resources and expertise are addressed through the increased adoption and usage of multidisciplinary and interdisciplinary collaboration. Multidisciplinary and interdisciplinary collaboration enables the sharing of new ideas and methods, resources, and skills, which benefits everyone involved.

A couple of studies have been undertaken to quantitatively measure the impact or influence of multidisciplinary and interdisciplinary collaboration (Braun and Schubert, 2003; Meyer, 2006). Braun and Schubert (2003) quantitatively measured the increased adoption of interdisciplinary and multidisciplinary approaches. Their study was accomplished by determining how frequently the terms multidisciplinary and interdisciplinary appeared in the titles of scientific journals articles and papers. The authors found that there was a variation in usage of these terms across the studied disciplines, with highest frequency occurring in life science. Braun and Schubert's (2003) indicated that the usage of multidisciplinary and interdisciplinary research had increased exponentially over the course of their studied timeframe, from 1980 and 1999. The revealing of such an exponential increase in the usage of multidisciplinary and interdisciplinary research is significant to the study of emerging disciplines. As disciplines emerge and develop, the influence and impact of multidisciplinary and interdisciplinary research on the discipline will dramatically increase.

Meyer (2006) addressed the question of whether or not patenting academic scientists within the discipline of nanotechnology were more productive scholars than their non-patenting counterparts. Traditionally, patenting and commercial activities are perceived as being in opposition to the goals, and objectives of academic research. Meyer (2006, p. 1648) noted that an increase in university patenting corresponded to a potential substitution of publications with patents, a reduction in instructional quality, and a limiting of the openness of academic culture. The academic culture is adversely impacted by the secrecy of innovation, the diversion of research resources, delayed publications, and the reduced communication that is a formalized part of the patenting process. Scholarly performance for Meyer's (2006) study was determined by measuring, and comparing the number of publication citations between 1992 and 2001 that each patenting and non-patenting scientist had. The completed citations counts were divided by publication performance rankings, which were determined by citation frequency. The academic scientists who publish and patent function well in both scientific research and technology development environments (Meyer, 2006, p. 1658). Further, inventing academics appeared to drive technological development within the academic environment in terms of patenting (Meyer, 2006, p. 1658).

4. Academic and Non-Academic Organizational Collaboration

The key element of each of the discussed research methodologies is collaboration. Since collaboration is a universal technique, this current review will focus on the use of collaboration within academic disciplines and environments. Academic institutions engage in a number of collaborative agreements with organizations of different types. The most common forms of these collaborations, academic-academic and academic-industry will be discussed. To operate effectively academic collaborations rely on the application of monodisciplinary, multidisciplinary, and interdisciplinary research approaches.

Substantially more research has been conducted on academic collaboration than there has on the application of citation analysis to academic research. Undertaken studies address a range of topics including: 1) the experiences of researchers faced with the introduction of interdisciplinary methodologies (Bruce et al., 2004), 2) the role of star academic scientists (Zucker and Darby, 1996; Zucker and Darby, 1997), 3) academic contributions to industrial innovations (Meyer-Krahmer and Schmoch, 1998), and 4) the impact of academic research spillover on local firm research and development spending (Jaffe, 1989).

Bruce et al (2004) investigated the experiences of researchers, and consortia within the European Union that were faced with the increasing need for collaboration that was generate by a growing lack of resources, materials, and funds for continued research. The authors found that interdisciplinary successes were closely associated with existing group structures such as contracts, consortia, and informal meetings (Bruce et al., 2004, p. 463). In terms of negative aspects, interdisciplinary approaches suffered from communication problems, discontent about the levels of participation, and the need for a common language to deal effectively with disciplinary terminology. The adoption of interdisciplinary techniques is further set back by the resistance generated by the academic systems within the European community's academic institutions (Bruce et al., 2004, p. 468).

Academic experience with collaborative methodologies extends beyond the traditional academic-academic linkages to include academic-industry collaborations. These academic-industry linkages or partnerships can be established in a number of ways. For instance, the series of studies undertaken by Zucker and Darby (1996; 1997) address the impact of star scientists who consult, and directly participate in industry or commercial environments and processes. Zucker and Darby (1996) addressed how the collaboration of star biotechnology scientists with firm researchers was indicative of successful commercial innovations and breakthroughs. Star scientists become key players in the development of emerging disciplines, and in the formation of innovative technologies and processes. Through collaboration, star scientists are able to transfer knowledge and research from the academic environment directly into the commercialization processes of industry. For Zucker and Darby (1996), the relationship between science and technology is represented more of a traffic circle than a two-way street. The commercialization of scientific research drives a short-term increase in the production of basic research, but this growth can be slowed or stopped if future scientific research is adversely impacted by the commercialized technologies. Zucker and Darby (1997) expanded on their previous research. Their later study revealed that scientists who engaged in commercial activities and/or partnerships annually produced significantly more publications then their purely academic counterparts.

Meyer-Krahmer and Schmoch (1998) examined industry-academic collaboration in an effort to determine which university disciplines were contributing to industrial innovations and processes. The study focused specifically on Germany's academic environment where professors have the choice of either being the patent applicant or selling their rights to the technology to an industry firm (Meyer-Krahmer and Schmoch, 1998, p. 837). The high levels of economic investment that are incurred in applying for and maintaining a patent are generating a sufficient incentive for academic researchers to seek out and establish industry partnerships. Meyer-Krahmer and Schmoch (1998) used such citation indicators as academic titles and affiliations, to determine the disciplines that had the greatest probability of being affected by academic-industry collaborations. The general concern about these types of collaboration is that industry objectives will generate a shift in the direction and production of academic research away from basic to applied. This concern stems from the commonly held belief that academic research is primarily oriented toward the production of basic research to begin with. Through the combined use of surveys, and citation analysis the authors found no support for this commonly held assumption (Meyer-Krahmer and Schmoch, 1998, p. 840). The authors also found that industry-academic collaboration was composed of stronger, and closer connections in application oriented or applied research disciplines than collaboration was in science-based disciplines (Meyer-Krahmer and Schmoch, 1998, p. 840). Further the authors revealed the existence of informal contacts or networks that were formed through academic-industry collaborations. These informal networks generated a two-way transfer of knowledge between academic and industry research, opposed to the unidirectional academic to industry transfer that is produced by contract work (Meyer-Krahmer and Schmoch, 1998, p. 841). Through the establishment of these types of two-way knowledge transfers academic and industry researchers benefit with sharing of ideas, skills, and experience.

Other research has shown that the geographic location of academic institutions has an impact on industry research and development spending, and the utilization of academic knowledge spillovers. Jaffe (1989) created a model to show that at the state level, university research in the United States had an impact on the geographic location of firm spending. The model's results indicated that commercial geographic spillovers were strongest in the disciplines of pharmaceuticals, chemistry, and electronics (Jaffe, 1989, p. 967-968). The flow of knowledge that is found within these geographic knowledge spillovers is unidirectional; in that basic academic research increases or drives industry research and innovation. Therefore, from a state level perspective within the United States, the success of local industry development can be increased by improving the quality of academic research institutions (Jaffe, 1989, p. 968). By improving the quality of academic research and institutions, a state can increase its potential for local innovation by attracting investment and collaboration from more firms and businesses.

5. Patent Valuation Methods

Based on the available literature, citation analysis is used in the two main categories of patent valuation, 1) knowledge based valuation (Sapsalis et al., 2006), and 2) economic based valuation (Trajtenberg et al., 1997; Reitzig, 2003; Reitzig, 2004). Both methods utilize the same information that is presented within the patent document. The utilized information includes: patent and non-patent literature citations, patent assignees, geographic locations of inventors and assignees, and application/granting dates. Of the two techniques knowledge valuation is the more prevalent, which is in part due to the more recent emergence of economic methods for patent valuation within the literature (Hall et al., 2005, p. 19). The knowledge valuation approach is used to determine a patent's value in correlation to the innovativeness, and usefulness of the technology, research or technical knowledge that the patent contains. The front page of the patent document contains numerous features and characteristics that allow for different forms of valuation. Patent and non-patent literature citations provide a clear and definable paper trail that represents the flow of knowledge into and out of the patent (Jaffe et al., 1993, p. 578). By measuring the amounts and types of backward patent citations (BPC[4]) the technical value of a patent can be determined. The technical value is representative of how novel the patented innovation or technology is. For instance, patents that cite a majority of publicly and academically produced patents are more closely associated with basic research, and therefore have higher levels of innovation (Trajtenberg et al., 1997; Sapsalis et al., 2006).

Measurements of the type and number of forward patent citations (FPC[5]) allows for a determination of the patent's value in terms of how useful the patented technology or innovation is (Trajtenberg et al., 1997, p. 26). This form of valuation operates on the premise that "if Patent X is cited by Patent Y, then X features a novel or useful piece of research or knowledge that is built upon by Y" (Jaffe et al., 1993, p. 580). The more Patent X is cited the greater the patent's perceived value becomes. Technological patent value is a form of knowledge valuation that operates through the measurement of FPC. A patent's technological patent value is calculated by averaging the total number of FPC that are accumulated within a set timeframe after the source patent's granting date (Mariani and Romanelli, 2007, p. 1135). The more FPC a patent receives through citation, the higher the patent's resulting technological patent value will be. As a method, technological patent valuation offers two primary benefits. First, the method allows for the valuation of single or specific variable, which allows for the effect or impact of that variable to be determined. Secondly, because this method utilizes FPC as the dependant variable, technological patent values can be effectively substituted for economic variables within a more extensive valuation process (Trajtenberg, 1990; van Raan and van Leeuwan, 2002; Sapsalis et al., 2006).

Sapsalis et al. (2006) utilized an econometric model to determine the effect of multiple variables, including citation type, self citations, assignees, and patent family

[4] BPC are citations contained within the source patent that refer to previously patented technologies and innovations

[5] Forward patent citations are citations contained in proceeding patents that reference the source patent

size on the technological impact of biotechnology patents. The biotechnology discipline was selected by the authors due the high levels of academic patenting. The number of FPC was used as the study's dependent variable, while the number of inventors and a time effect for patent age where used as controls (Sapsalis et al., (2006). The connection to technical knowledge was perceived as being through the use of BPC. Information regarding the patent assignees was divided into three categories (1) corporate, 2) public, and 3) self citations) for the purpose of determining the origins of the technical research (Sapsalis et al., 2006). In comparing industry produced patents to academically produced patents, the authors found that both sets of patents reacted similarly to the study's determinants. First, BPC and coassignees were found to have significantly positive effects on the generation of FPC (Sapsalis et al., 2006, p. 1638). Secondly, an opposition between industry and academic patents was found in terms of the number of inventors. For industry patents greater numbers of inventors resulted in higher levels of citation, while the opposite was found to be true of academic patents (Sapsalis et al., 2006, p. 1640). The third set of results addressed the usage of non-patent literature citations (NPLC[6]) and self citations. The usage of NPLC was also found to be a point of distinction between the two sectors. For the academic sector NPLC had no significant impact, while in the corporate sector these citations had a significantly negative impact (Sapsalis et al., 2006, p. 1640). In terms of self citations, self patent citations were found to add to patent value, while self NPLC decreased a patent's technological value (Sapsalis et al., 2006, p. 1640). Through the usage of self citations, the inventor or researcher is able to demonstrate their expertise within a technical area. As a result a dichotomy in the perception of the researcher's skill is generated by the usage self citations. Through the usage of self BPC the inventors is perceived as possessing a specialized area of knowledge, while the public nature of self NPLC is perceived as being more generalized and basic.

Within the literature economic processes and methods for the valuation of patents have more recently emerged. Economic methods for patent valuation are

[6] NPLC are citations made to literature, excluding patents, which include such forms as academic journals, books, conference proceedings, etc

utilized to determine a patent's value either monetarily or in terms of the probability that a specific event will occur. Value is determined through the usage of both direct correlation, and latent variables. Direct correlation variables include: prices, costs, and product quantities sold, whereas latent variables include: novelty of the technology, scientific breadth, level of technological innovation, and difficulty to invent around the technology (Reitzig, 2004, p. 940). Both of these variable sets, in addition to the geographic locations of inventors, assignees, and the scope of patent protection, can all be used to determine a patent's economic value.

Geographic location, whether that of the inventor, assignee or the countries the patent is protected in, is used to determine the economic value of the patent in terms of knowledge spillover. Knowledge spillover is research, technology or technical knowledge that is derived by either an industry or academic organized, and that is used by other agencies in either research or technological development. From an economic standpoint higher levels of knowledge spillover from a document, generate more research or technology, which in turn increases the contributions made to local or national economies. Studies by Jaffe et al (1993), and Mansfield and Lee (1996) have utilized geographic locations to track knowledge flows through the usage of patent citations to indicate how these knowledge flows benefit the local or national economy. Jaffe et al (1993) compared the geographic location of citations with the location of the source patent to determine the significance of location in knowledge spillovers. The authors found that the significance of geographic location reduces with time, and that geographic location is not indicative of knowledge spillover (Jaffe et al., 1993, p. 596). The authors also found that knowledge spillover was associated more basic research than applied research. This association is generated by the fact that very basic research has less of a probability of being patented, and therefore is more likely to be transferred through publications and networks (Jaffe et al., 1993, p. 584).

Mansfield and Lee (1996) looked at how a university's distance from industry firms affected the percentage of industry support, and funding for research and development. Their study focused on seven major disciplines, which included biochemistry, electrical engineering, and computer science. To determine the effect of geographic distance the authors focused on three main variables: 1) regional effects, 2) amount of research and development spending, and 3) faculty quality (Mansfield and Lee, 1996). The authors found that the amount of industry support for research and development of universities located within a hundred miles was ten times greater than that for universities that were further away (Mansfield and Lee, 1996, p. 1056). The benefits of industry support were found to be a two way relationship. Universities within a hundred miles of the industry firm received funding to supplement the decreasing amounts of federal and governmental funding, and the firms within the same distance gained the opportunity to be the first to apply the produced research (Mansfield and Lee, 1996, p. 1056).

Beyond geographic location and knowledge spillover, the economic approaches to patent valuation incorporate monetary values, and probability of a specific event occurring. Studies which utilize economic methods have focused on the specific aspects of a patent's novelty, and potential for competition (Reitzig, 2004). The variables that have been used in these types of studies include: costs (development, patenting, and production), sold quantities of the patented product by the patent owner, and royalties (Reitzig, 2004, p. 940). Typically, patents that have low levels of competition and high levels of innovation have higher values. In these types of studies economic value is determined in terms of established profits; therefore higher profits are equivalent to higher patent values.

6. Limits of Current Research and Conclusion

The range of literature regarding the use and application of citation analysis is quite extensive. Studies by Bruan and Schubert (2003), Meyer (2006), and Zucker and Darby (1996; 1997) have shown that interdisciplinary and multidisciplinary forms of research are increasing in usage, and that the scientists who are utilizing these forms are more productive. Other applications of citation analysis have been found to include: 1) patent valuation (Lerner, 1994; Harhoff et al., 1999; Guellec and van Pottelsberghe de la Potterie, 2000; Sapsalis et al., 2006), 2) the determination of changes in academic licensing practices (Mowery et al., 2001; Saragossi and van Pottelsberghe de la Potterie, 2003), 3) determining the impact of geographic location

(Jaffe et al., 1993; Mansfield and Lee, 1996), and 4) determining the effect of different patent or researcher characteristics (Reitzig, 2003; Reitzig, 2004; Mariani and Romanelli, 2007). Still other studies have applied citation analysis to understanding how basic science is linked to technology development (Narin, 1994; Mansfield and Lee, 1996; Narin et al., 1997; Meyer 2000; Thursby, J. and Thursby, M., 2002; von Wartburg et al., 2005).

Even with the combined extent of all of these studies, there are still gaps in the understanding of the effects of multidisciplinary and interdisciplinary research and collaboration. One of the more prominent gaps is how these collaborative research forms effect the knowledge valuation of patents within emerging techno-scientific disciplines. Even though economic patent valuation techniques are increasing in usage, knowledge valuations methods are the more suited for determining the effect of multidisciplinary and interdisciplinary research. Knowledge based valuation methods enable the determination, understanding, and measurement of how scientific research is being utilized within patent documents.

As the usage of multidisciplinary and interdisciplinary research increases as disciplines continue to emerge and develop, there is an uncertainty about effect of these collaborative forms on the technology development and patenting processes. This effect is especially relevant to emerging techno-scientific disciplines, such as biotechnology, that are oriented towards technology development. The uncertainty that is generated by the usage and effect of collaborative research methods has created a gap within the existing literature. Therefore, the key question that needs to be addressed is whether or not multidisciplinary and interdisciplinary research has any effect on the technology patent value of patents within an emerging techno-scientific discipline.

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Chapter 2: The Effect of Collaborative Research on Technological Patent Value

1. Research Introduction

Interdisciplinary and multidisciplinary research is continuing to be utilized, and established within emerging techno-scientific disciplines[7] and research. Disciplines, such as nanotechnology, biotechnology, and biochemistry are built upon or have emerged out of multidisciplinary and interdisciplinary research and collaborations (Lerner, 1994; Thursby, J., and Thursby, M., 2002; Sapsalis et al., 2006). Within these types of disciplines, the scope of the roles, values, and benefits of multidisciplinary and interdisciplinary research is extensive and diverse. The benefits of multidisciplinary and interdisciplinary research encompass: 1) increased opportunities for the publication or patenting of research, 2) researcher prestige (Hicks, 1995), 3) emergences of new areas or disciplines of study (Lerner, 1994; Thursby, J. and Thursby, M., 2002; Sapsalis et al., 2006), 4) the solving of complex socio-scientific problems (Mansfield and Lee, 1996; Mowery et al., 2001; Saragossi and van Pottelsberghe de la Potterie, 2003), 5) increased sources of funding or resources, and 6) the enablement of access to sources of cutting edge or current research, and technology (Hicks, 1995). These benefits make collaborative research a suitable choice for use with such commercial activities as technology development, and patenting.

One of the more prominent usages of multidisciplinary and interdisciplinary research is its utilization in developing novel, innovative or useful solutions to the complex socio-scientific problems that are researchers are currently facing. This aspect of novelty and innovation makes collaborative research suited for usage within the patenting process. The competitive and regulative nature of the commercialization process requires that granted patents incorporate elements of

[7] Techno-scientific disciplines are disciplines that are strongly science based and oriented toward technology and innovation production

novelty and usefulness. Since multidisciplinary and interdisciplinary research is used to generate these specific aspects or characteristics, usage of these forms collaborative research will potentially add value to a patent document. Any increase generated by collaborative research within a patent, would be generated by increases in the quality, and innovativeness of the research and knowledge that is being used. Knowledge valuation methods, such as technological patent value, can be used to determine and measure changes in patent value. Technological patent valuation is a citation analysis method that determines value through the number of citations a document receives. Even though there appears to be a logical correlation between collaborative research and the patenting process, the relationship between collaborative research and the patenting process has not been directly addressed in the literature.

The available literature on multidisciplinary and interdisciplinary research is composed of a broad range of topics which comprise: 1) the impact of industry-academic collaborations (Meyer-Krahmer and Schmoch, 1998), 2) the role of top academic researchers (Zucker and Darby, 1996; Meyer, 2006), 3) the geographic distribution of knowledge (Mansfield and Lee, 1996; Zucker et al., 1998), 4) the commercialization of academic research (Mansfield, 1998; Mowery and Ziedonis, 2002; Owen-Smith and Powell, 2003), and 5) the determination of patent value (Lerner, 1994; Harhoff et al., 1999; Guellec and van Pottelsberghe de la Potterie, 2000; Reitzig, 2003; Reitzig, 2004; Hall et al., 2005; Sapsalis et al., 2006). Even with this extensive range of research there are still gaps present in the understanding of the effects, benefits, and limitations of multidisciplinary and interdisciplinary research and collaboration. One the more prominent of these gaps is the lack of understanding of how these collaborative research forms affect the technological patent value of patented technologies, especially within emerging techno-scientific disciplines. The current study is directed towards addressing this gap within the literature.

Emerging techno-scientific disciplines, such as biotechnology, are built upon or incorporate multidisciplinary and interdisciplinary research, and are targeted towards the patenting of new technologies and innovations[8]. The combination of this point with the fact that the patenting process is composed of high levels of investment

[8] Innovations are patented concepts, methods or ideas

and regulation indicates that there is a need to understand how the value of new technologies and innovations is being affected by collaborative research. The main question that needs to be addressed is: how does multidisciplinary and interdisciplinary research and collaboration affect the technological patent value of patents within an emerging techno-scientific discipline?

The biofuels discipline provides an ideal setting to address this specific question. The biofuels discipline is an emerging techno-scientific discipline that encompasses a crossroads of scholarly research, and technological development. More specifically, the biofuels discipline draws upon a variety of research that is produced by a number of distinct disciplines including microbiology, agriculture, biology, chemistry, biotechnology, and engineering. Beyond drawing on and incorporating a wide range of research the biofuels discipline is socially and politically influenced. Particularly, the discipline is perceived as being a potential source of solutions for the growing socio-scientific problems of 1) climate change, 2) biomass conversions, and 3) finding a cost effective, and sustainable source of energy. By being the center of public and political attention, the discipline has within the last decade seen substantial levels of investment by governments, academic agencies, non-profit organizations, and industries. In 2007, the United States Departments of Agriculture and Energy announced the awarding of $8.3 million in funding to 11 bio-based fuel research projects, for the purpose of accelerating the development of alternative fuel resources (US Department of Energy, 2007). In 2006, the Alberta provincial government announced the investment of $238 million over a five year period for the purpose of strengthening and expanding Alberta's bioenergy sector, with $24 million being invested in biofuels (University of Alberta, 2006).

Through the increased investment the biofuels discipline has been directed more towards the production of applied research, and technology and innovation development. As a result a number of the produced technologies and innovations have been granted patent protection. The innovativeness and novelty of patented technologies can potentially be increased through the usage of multidisciplinary and interdisciplinary scientific research. Thus, the integration of research that is generated by these collaborative forms into biofuel technologies and innovations will be reflected in the technological patent values of the biofuel patents. Proposition 1 of this study is that patents that utilize multidisciplinary and/or interdisciplinary academic scientific research will feature higher technological patent values than those that do not.

As previously discussed the benefits of multidisciplinary and interdisciplinary research are quite varied, and include: 1) more publication or patenting opportunities, 2) increased access to funding or resources, and 3) access to cutting edge research and technology. Because of these perceived benefits multidisciplinary and interdisciplinary research will potentially be incorporated into patents at a more rapid rate than other established forms of research. Therefore, Proposition 2 of this study is that the multidisciplinary and interdisciplinary research that is integrated into biofuel patents will be current or cutting edge, and therefore will have lower citation ages.

The biofuels discipline has not been addressed by any studies regarding either the usage or effect of multidisciplinary and interdisciplinary research or any citation research regarding patents. Due to the lack of previous research, a study of the biofuels discipline will require an exploratory approach. Although the primary goal of this research is to determine the effect of multidisciplinary and interdisciplinary research on technological patent values, there are a number of other factors that must be understood first. These factors comprise: 1) the identification of the sources of multidisciplinary and interdisciplinary research, 2) the determination of who is using the research and how, and 3) the determination of citing agents and citation types. The exploration of each of these factors will allow for both propositions to be addressed.

2. Methodology

Due to the usage of an exploratory approach this study has three main objectives. The first objective is to understand how and by whom the multidisciplinary and interdisciplinary research is being integrated into the biofuel patents. No proposition is used to address this objective rather the compiled data from this objective will be used to provide a clearer understanding of the usage of collaborative research within the discipline. The second objective is to understand how the shift in the organizational form from a monodisciplinary to multidisciplinary and interdisciplinary research approach affects the technological patent value of biofuel patents. The results of this objective are used to address Proposition 1. The final objective, which is addressed by Proposition 2, looks at the currency of the multidisciplinary and interdisciplinary research that is being utilized in the patents.

To address these specific objectives, this study utilizes a systematic, quantitative, exploratory approach to test the two key propositions that have been previously discussed. The application of such an approach allows for the compilation of basic empirical data, such as citation counts, descriptive statistics, and distributions, which can provide an understanding the effect of multidisciplinary and interdisciplinary research on technological patent valuation. The empirical data collected in this study can be used in or incorporated into future research that incorporates more advanced mathematical models.

The data for this study was manually extracted and compiled on a patent by patent basis directly from the United States Patent and Trademark Office (USPTO) website. The USPTO was selected primarily for the availability, and accessibility of biofuel patents, in addition to the clear and organized layout of citations contained within the patents. Multiple searches were conducted using the following key word variations and combinations: biofuels, bio-fuels, bio and fuel, biodiesel, bio-diesel, bio and diesel, methanol, methanol and fuel, ethanol, ethanol and fuel, and triticale. It should be noted that the selection and combination of search words has been derived solely by the author, with no conciliation by individuals working within the biofuels discipline. All variations of these search words were entered into combinations of title, abstract, and title and abstract within the USPTO's search engine. With the removal of duplicate patent entries, the searches generated a total of 227 granted patents relating to biofuel technologies and innovations between 1 January 1975 and 31 December 2002.

The objectives of this current study were addressed through the usage of a five step methodology. The first step within the methodology dealt with the identification of research, literature, and citation types and sources. The primary purpose of this step was to determine where the multidisciplinary and interdisciplinary research that was being integrated into the biofuel patents was being drawn from. The determination of the research origins provides an indication of not only the citation type, but also how the research is being used. This step involved the compilation of the citation data that was extracted from each of the 227 source biofuel patents. The extracted information included: 1) forward patent citations (FPC[9]), backward patent citations (BPC[10]), and non-patent literature citations (NPLC[11]), 2) patent assignees, 3) patent filing and granting dates, 4) citing agents, and 5) citation types. The source set of biofuel patents was found to reference a total of 2327 BPC and 946 NPLC, and were referenced by 2905 FPC. The three categories of citations were associated with two main types of literature, patent and non-patent. Patent literature is composed of previous patents that feature similar technologies, innovations or designs to the patented technology. Non-patent literature is composed of all the other potential sources of information which include: 1) academic journals, 2) industry, and trade publications, 3) conference proceedings, 4) books, and 5) all other forms of literature and media (Meyer, 2000a).

Research sources were identified through the usage of publication titles, associated disciplines, and literature type. Four types of patents were identified on the basis of the incorporation of NPLC types. These categories included: 1) patents with no NPLC, 2) patents with no academic NPLC[12], 3) patents with no multiple academic NPLC[13], and 4) patents with multiple academic NPLC. Self citations in all of the FPC, BPC, and NPLC were identified by compiling the names of all the inventors. Self citations are citations that an author or inventor makes to their own previous research or publications (Katz and Hicks, 1997; van Raan and van Leeuwan, 2002).

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[9] FPC are citations contained in proceeding patents that refer to the source patent

[10] BPC are citations contained within the source patent that refer to previously patented technologies and innovations

[11] NPLC are citations made to literature, excluding patents, which include such forms as academic journals, books, conference proceedings, etc.

[12] Academic NPLC are citations made specifically to academic journals

[13] Multiple academic citations are multidisciplinary and interdisciplinary citations contained within the academic literature that feature two or more authors from distinctly different disciplines

Information regarding inventors, and patent filing and granting dates was directly compiled from each of the source patents, and the corresponding FPC and BPC. The information compiled from the NPLC included: 1) article publication date, 2) publication title, 3) article title, 4) corresponding patent number, 5) author(s) name(s), 6) author affiliation (department, institution, and location), and 7) the citing agent responsible for the use of the cited reference. All of the extracted data was compiled according to patent number into a single document.

The second step in the methodology determined the types of research citations in terms of the number of authors, the author's organizational affiliation, and the collaborative form. The compiled citations were divided into two categories of single, and multiple that corresponded to the three primary forms of collaborative research: 1) monodisciplinary, 2) multidisciplinary, and 3) interdisciplinary. Single citations represent monodisciplinary research, in that they feature one or more authors from the same discipline. Multiple citations represent multidisciplinary and interdisciplinary research, in that these citations incorporate knowledge and research that is generated through the collaboration of two or more disciplines.

Two categories of citations are used due to the difficulty of distinguishing between multidisciplinary and interdisciplinary research within the patent and non-patent literature (Tijssen, 1992). The difference between the two methods is in how problems are addressed. Through multidisciplinary research problems are addressed through a divisionary approach. With this approach individual researchers or research groups from distinctly different disciplines work on segments of a common problem with little or no collaboration. Once completed each of the researcher's results is combined into a single solution. Interdisciplinary research also operates with researchers or research groups from distinctly different disciplines. The difference is that these researchers are either working as part of the same team or with moderate to high levels of collaboration. The primary problem that interdisciplinary research encounters is communication barriers, in terms of terminology, and methodologies. Therefore, this type of collaboration requires a cognitive change to occur in the individual researcher's world and scientific perspective, methodologies, skills, and communication.

The categories of single and multiple citation types are further divided into six categories, which are based on the disciplinary or organizational affiliation of each author. The two primary sources of NPLC are 1) academic organizations, and 2) industry organizations. The three dividing categories are generated for both single and multiple citations include: 1) academic, 2) non-academic, and 3) mixed (a combination of academic and non-academic citations). Each of the six generated citation types is defined as follows:

Single-academic: research that is conducted within a single academic discipline. This collaborative method has traditionally been associated with universities, and other academic institutions.

Single-nonacademic: research that is conducted within a single discipline by nonacademic organizations, such as industry or non-profit organizations or government agencies.

Single-mixed: research that is conducted through the collaborative efforts of academic and nonacademic organizations within a single discipline.

Multi-academic: research that is conducted by two or more academic agents from distinctly different disciplines or fields, for example: environmental microbiology and inorganic chemistry.

Multi-nonacademic: research that is conducted by two or more nonacademic agents that operate in distinctly different disciplines or fields.

Multi-mixed: research that is conducted by academic and nonacademic agents from distinctly different disciplines or fields.

The third methodological step involved the determination of all citing agents, patent assignees, their roles, and associated citations. Citing agents were identified as the individuals within the patenting process who were responsible for adding, and using citations in the patent document. This study identified that the two main citing agents that were responsible for the citations contained within the patents were the patent applicant, and the patent examiner. Citations selected by the patent applicant are used to reference the prior art that is relevant to the technology. Research, specifically multidisciplinary and interdisciplinary research is integrated directly into the patented technology through the applicant's citations. Citations that are utilized by the patent examiner are used to define or create a boundary around the technology, within which the technology is novel, innovative, and useful (Narin and Noma, 1985; Jaffe et al., 1993; Narin et al., 1997; Meyer, 2000a; von Wartburg et al., 2005). Patent assignees were recognized as the individual(s) or organization(s) that held the rights to the patent. Four categories of patent assignees were identified in correlation to the sector of research and included: 1) industry, 2) academic, 3) public, and 4) individual and unknown.

The fourth step of the methodology addressed Proposition 2 by examining the currency of the incorporated multidisciplinary and interdisciplinary research in terms of each article's citation age. Citation ages were calculated specifically for each of the 544 NPLC due to the fact that these sources of research prominently contain the multidisciplinary and interdisciplinary research. This set of data compiled all of the NPLC that were cited by the 227 source biofuel patents between 1975 and 2002. Collins and Wyatt's (1988, p. 67) following formula was used to calculate the citation age of each of the available academic NPLC:

Citation age = Patent granting year – Article's year of publication

The final step of the methodology involved the determination of the technological patent value of each patent, and the T Testing of the technological patent value means for statistical comparison. Technological patent value is representative of the value of the technology, in terms of the usage of the knowledge, research or technology contained within the patent. This current study utilized the Forward5 method to calculate the technological patent value of each biofuel patent. The Forward5 method operates by averaging the number of FPC that accumulated within the first five consecutive years after the patent's granting date (Mariani and Romanelli, 2007). This method was selected for two key reasons. The first is that the Forward5 method allowed for the largest sampling of biofuel patents in correlation to calculated technological patent values. The second reason is that publications that are not cited receive a citation within the first five years of their publication date are either forgotten or remain unused (Crane, 1972). The calculated technological patent values were used to divide the entire dataset into sets of descriptive statistics for the purpose of using Welch's unpaired T Tests to compare the statistical relevance of the data.

To understand whether or not multidisciplinary and interdisciplinary research had any effect on technological patent values a quantitative statistical comparison was needed. T Tests were selected as the primary form of analysis due to the fact that these types of tests allowed for the comparison of independent variables in correlation to a single dependent variable. Since there is an uneven distribution of randomly generated samples within the datasets compiled by this research, a test that did not require paired data was also needed. Welch's unpaired T Test fit with the objectives and the analysis requirements of this current study. The unpaired aspect of the test allowed for the comparison of uneven datasets. Being a T Test, Welch's method operates with the assumption that the data is randomly generated, and with the null hypothesis that there is no difference between the two tested groups in relation to the dependant variable. The other factor of Welch's T Test that should be considered is that the T values can be either negative or positive depending on the difference between the means. The P value that is produced by the T Test is the probability that, assuming the null hypothesis is true, the data would be observed.

This current study utilized Welch's unpaired T Test to determine the statistical relevance of the usage of NPLC, multiple academic NPLC, and self citations (FPC, BPC, and NPLC), to the technological patent value of biofuel patents. The dependant variable for all of the tests was technological patent value. The tested treatment variables were all randomly generated and uneven the distribution of samples within each dataset. The results compiled from Steps 1 through 3 were examined in conjunction with the calculated P values for the purpose of addressing Proposition 1. All of the Welch's T Tests were conducted using the Graphpad statistical program, which is available online.

3. Results

3.1. Sources of Scientific Research within Patents

The number and percentage of patents corresponding to each patent category is displayed in Table 1. Only 37.69% of the source patents cited research that was taken from academic sources, while a mere 14.29% of the patents cited multidisciplinary and interdisciplinary research.

Table 1: Referenced citations

Utilized Citations	# of Patents	% of Patents
No NPLC	133	40.43
No academic NPLC	72	21.88
No multiple academic NPLC	77	23.40
Multiple academic NPLC	47	14.29

The usage of NPLC within the biofuels discipline by the primary citing agents between 1975 and 2002 is depicted in Table 2. Academic publications, in the form of academic journal articles dominate the type of citations used by each of the citing agents. Thus, academic publications are the primary source of multidisciplinary and interdisciplinary scientific research.

Table 2: NPL publication types

	Applicant	Examiner
Academic Publications	260	333
Industry Publications	18	47
Books	60	46
Conference Publications	37	30
Other - nonscientific	25	90

The academic journals that are cited within biofuel patents represent six fields of research, which are displayed in Table 3. A total of 97 academic journals were cited by the 227 patents, with the majority of scientific research being drawn from biology, and multidisciplinary oriented journals. Biology and multidisciplinary journals[15] account for 40.81% and 27.15% of the cited academic citations respectively. The top three journals that featured in the highest amounts of NPLC were: 1) The Journal of Bacteriology, 2) Applied and Environmental Microbiology, and 3) Biotechnology and Bioengineering. Only one of these most cited journals, Biotechnology and Bioengineering, is specifically a multidisciplinary publication. Since the biofuels discipline is a multidisciplinary discipline, it is logical that a significant portion of the scientific research the discipline utilizes be multidisciplinary and interdisciplinary.

Table 3: Research fields

Field	# of Journals	Total Cites	Single Citations	Multiple Citations	Applicant Citations
Agriculture and food	7	9	3	1	4
Biology	30	241	76	20	96
Chemistry	22	82	28	4	32
Engineering	10	37	15	7	22
Medicine	2	10	2	4	6
Multidisciplinary	26	161	52	16	68

3.2. Research Citation Types and Distribution

Within this study citations were examined in two phases. The first phase looked at how each citation type (FPC, BPC, and NPLC) was used by each patent assignee (1) industry, 2) academic, 3) public, and 4) individual/unknown). These usages are displayed in Tables 4, 5 and 6 of this section. This initial examination of the usage of the FPC, BPC and NPLC provides insight into how knowledge and research is being integrated into, and transferred from the patent document. The second phase looked at the specific usage of each of the six single and multiple citation types, discussed in the Methodology section, by the applicant. The breakdown of the total cited NPL by citation type, and technological patent value as it corresponds to both the patent examiner and applicant is depicted in Tables 13 to 18 of the Appendix. Specifically, this set of tables provides an indication of how applicant and examiner citations relate to the technological patent value of each of the source patents. Tables 19 to 25 of the Appendix display a breakdown of citations based only on the citations used by the applicant. This specific set of tables focuses specifically on how the multidisciplinary and interdisciplinary research that is directly integrated into the development of the technology corresponds to the technological patent value of the patent.

Table 4: Forward patent citation information

Forward Patent Citations (FPC)	Industry	Academic	Public	Individual/ Unknown	Total
Average number of FPC per patent	11.88	15.29	14.02	11.59	10.25
% of patents cited at least once	96.43	95.12	97.30	86.49	95.15
% of total self FPC	32.56	51.94	13.18	2.33	100
Average number of nonself FPC per patent	11.50	13.66	13.56	11.51	12.23
Average number of self FPC per cited patent	2.10	2.79	1.89	1.50	2.35

Table 4 displays the patent assignee usage of the 2905 FPC, which cite the 227 source biofuel patents. The distribution of the average number of FPC per patent is reasonably consistent across each of the patent assignees. This consistency indicates a consistent usage of biofuel technology, research, and technical knowledge through all research sectors. Academically held patents feature the highest amount of self FPC, composing 51.94% of the total self FPC. This indicates that academic researchers are more likely to cite and utilize their own previous research, than their non-academic counterparts. A summary of the usage of BPC in correlation to the patent assignees is displayed in Table 5. Again, the average number of citations is found to reasonably consistent across the patent assignees with the exception of public assignees. Public assignees appear to rely more strongly on previously produced technologies, and technical knowledge, as indicated by the average of 17.22 BPC per patent. Academically held patents featured the lowest percentage of patents that featured at least one BPC with 87.80%. Industry assigned patents utilized the majority of self BPC with 38.57% of the total self BPC.

Table 5: Backward patent citation information

Backward Patent Citations (BPC)	Industry	Academic	Public	Individual/ Unknown	Total
Average # of BPC per patent	7.06	7.78	17.22	8.81	9.13
% of patents cited at least once	98.21	87.80	100	100	96.92
% of total self BPC	38.57	28.57	28.57	4.28	100
Average number of nonself BPC per patent	6.82	7.29	16.68	8.73	8.82
Average number of self BPC per cited patent	1.59	1.54	2.00	1.00	1.63

NPLC provided the primary source of multidisciplinary and interdisciplinary scientific research within the patent document. Table 6 displays the breakdown and usage of NPLC by patent assignee. The average number of NPLC per patent is similar for all assignees, with the exception of publicly held patents. Public assigned patents average 2.62 NPLC, and 1.30 academic NPLC per patent, which are the lowest amounts in each category. Such low values indicate a low usage of publicly produced research. As seen in Table 6 the majority of patents, regardless of patent assignee feature at least one NPLC. In terms of patents containing academic NPLC, industry held patents compose the majority with 41.96% of industry held patents citing at least one academic NPLC. Academically held patents utilize the greatest usage of self NPLC with 24.39% of academically held patents. As displayed in Table 6, the majority of the utilized self citations are attributed to the patent examiner. Therefore, these citations are used to define the patented technology rather than being integrated into. The dominate usage of academic NPLC by the patent examiner is found in industry, public and individually held patents. In terms of academic patents the usage of academic NPLC is equally divided between the examiner and the applicant at 9.95%.

Table 6: Non-patent literature citation information

Non-Patent Literature Citations (NPLC)	Industry	Academic	Public	Individual/ Unknown	Total
Average # of NPLC per patent	4.40	4.49	2.62	4.65	4.17
% of patents with NPLC	63.39	53.66	51.35	67.57	60.35
Average # of academic NPLC per patent	2.83	2.88	1.30	2.97	2.61
% of patents with academic NPLC	41.96	36.59	35.14	43.24	40.09
% of patents with self academic NPLC	0	24.39	13.51	2.70	7.05
% of total academic self NPLC - examiner	0	57.33	9.33	0	66.67
% of total academic self NPLC - applicant	0	24.00	6.67	1.33	32.00
% of total academic NPLC - examiner	31.87	9.95	4.89	9.44	56.16
% of total academic NPLC - applicant	21.59	9.95	3.20	9.12	43.84

The 1975 to 2005 distribution of NPLC by citation type can be seen in Table 7. Increases in the usage of both single, and multiple citation types can be seen over time. Distinct increases in the usage of single and multiple citations can be seen over time. This increased usage could be generated in response to the increased production, and availability of research, and technical knowledge within the emerging discipline. More specifically, this increasing trend is reflected in the usage of single academic and single non-academic citations. In terms of multiple citations only marginal increases can be seen in the usage of multi academic and multi mixed citations. The increase availability of multi mixed citations could reflect an increase in either industry funding or academic-industry partnerships within the discipline.

Table 7: Distribution of academic references by citation type

Granting Date	Total Academic Cites	Total Single Citations	Total Multiple Citations	# of Single Academic	# of Single Nonacademic	# of Single Mixed	# of Multi Academic	# of Multi Nonacademic	# of Multi Mixed
1975 to 1980	50	44	5	26	15	3	2	0	3
1981 to 1985	65	63	2	32	28	3	2	0	0
1986 to 1990	64	57	6	46	11	0	1	2	3
1991 to 1995	188	155	33	108	47	0	14	3	16
1996 to 2000	320	243	73	160	79	4	36	6	31
2001 to 2005	231	175	52	132	37	6	20	4	28

3.3. Patent Citing Agents

Table 8: Percentage of academic NPLC types by citing agent

Citing Agent	Total Cites	Total Single Citations	Total Multiple Citations	Single Academic	Single Nonacademic	Single Mixed	Multi Academic	Multi Nonacademic	Multi Mixed
Applicant	42.38	34.94	7.43	23.98	10.97	0.19	2.42	0.56	4.46
Examiner	57.62	50.00	7.62	34.57	14.13	1.30	3.72	1.30	2.42

As depicted in Table 8, the majority of NPLC at 57.62% are attributed to the patent examiner. The values calculated in Table 8 are based on a total of 538 academic NPLC, opposed to the original academic NPLC total of 593. The 55 citation difference is caused by either the citing or referencing of incomplete, partial citations by the patent examiner or applicant, or by the fact that the publication was unavailable. This specific division indicates that the cited NPLC are being primarily used to define the uniqueness of the patented technology. The patent examiner is also responsible for utilizing the majority of single citations. The usage of multiple citations is almost equally divided between the applicant and the examiner. The applicant's usage of multiple citations composes 7.43% of academic NPLC, while the examiner utilized 7.62%.

Research is integrated directly into the patented technology through the use of applicant citations. The applicant usage of each citation type between 1975 and 2002 is displayed in Table 9. Table 9 indicates a steady increase in the usage of single citations, specifically single academic citations. Additionally, marginal increases in applicant's usage of multi academic and multi mixed citations can also be seen. Based on the overall citation usage and the applicant's usage of citations, the integration of multidisciplinary and interdisciplinary research into biofuel patents is marginal at best.

Table 9: Applicant usage of citations

Granting Date	Total Cites	Total Single Citations	Total Multiple Citations	# of Single Academic	# of Single Nonacademic	# of Single Mixed	# of Multi Academic	# of Multi Nonacademic	# of Multi Mixed
1975 to 1980	5	5	0	2	3	0	0	0	0
1981 to 1985	50	43	7	20	22	1	3	0	4
1986 to 1990	8	8	0	6	2	0	0	0	0
1991 to 1995	29	24	5	20	4	0	0	1	4
1996 to 2000	126	98	28	72	26	0	9	2	17
2001 to 2002	15	13	2	4	4	0	1	0	1

3.4. Citation Ages of Utilized Research

This set of results represents the testing of Proposition 2, which states that multidisciplinary and interdisciplinary research will have lower citation ages as it is cited closer to the research's publication date. Table 10 displays the citation ages of the cited academic NPLC in relation to the corresponding citation type. If multidisciplinary and interdisciplinary research was being utilized as quickly as it was published, then the multiple citations would have consistently lower citation ages. As Crane (1972) indicates, publications that are not cited within five years of their publication date are generally forgotten or are not used. Therefore, current or cutting edge research will feature a citation age of five years or less. Based on the results displayed in Table 10, none of the citation types display a prominent reliance on the usage of current or cutting edge research. There are multiple factors that can account for this pattern. The potential first factor is the relevance of the current research to the patented technology. The less relevant the current research is, the less likely the research will be cited or used. A second factor is the researcher's assess to, and familiarity with the publications the research is published in. A third potential factor is the type, geographic coverage, and quality of the publication that the research is published in. The quality of the publication can influence how a researcher perceives research. Research published in top publications may be perceived as being more valuable or useful to a researcher, and may therefore be integrated into a patent.

Table 10: Citation ages and types

Citation Age (Patent Granting Date)	Single Academic	Single Nonacademic	Single Mixed	Multi Academic	Multi Nonacademic	Multi Mixed
1	3	3	0	0	0	0
2	10	2	1	0	1	1
3	20	11	1	1	1	1
4	31	8	0	3	0	4
5	24	14	1	0	1	2
6	24	12	0	1	1	3
7	26	19	1	3	0	4
8	21	7	1	4	0	6
9	32	5	0	4	1	3
10	18	9	0	2	0	2
11	13	5	3	1	0	1
12	13	5	0	1	0	2
13	9	4	0	3	0	2
14	5	1	0	1	1	1
15	7	4	0	0	0	0
16 to 20	31	5	0	5	4	5
21 to 30	11	10	0	3	0	0
31+	15	11	0	2	0	1

3.5 Technological Patent Valuation

A series of Welch's unpaired T Tests were conducted on the data to determine the relevance of such factors as NPLC, academic multiple disciplinary citations, and self citations. The T value for each conducted test is displayed in Table 11. The first set of T Tests was conducted on the 227 source patents to determine the statistical relevance of using NPLC. This test compared patents containing NPLC (Treatment 1) to patents that did not contain NPLC (Treatment 2). Based on the T value indicated in Table 11, it was found that the usage of NPLC was not statistically significant. Thus, the usage of NPLC has no direct affect on the technological patent value of biofuel patents. A second test was run comparing the statistical relevance of patents containing multiple academic NPLC (Treatment 1) to patents containing only single academic NPLC (Treatment 2). The resulting T value indicated that the usage of multiple academic NPLC was not statistically significant. This suggests that the usage of multidisciplinary and interdisciplinary research does not affect technological patent values.

Table 11: T Test Results

Treatment 1	Mean	Standard Deviation	Sample #	Treatment 2	Mean	Standard Deviation	Sample #	T Test Value	Degree of Freedom	P-Value
NPLC	0.91	1.38	79	No NPLC	1.05	1.72	149	-0.6437	187	0.5205
Multiple academic NPLC	1.12	2.06	12	Single academic NPLC	0.65	1.09	40	1.0732	52	0.2882
Self citations	1.14	1.37	84	No self citations	0.59	0.93	143	3.2143	128	0.0017
Self FPC	1.43	1.43	54	No self FPC	0.59	0.95	173	4.0843	69	0.0001
Self BPC	0.66	0.90	42	No self BPC	0.83	1.19	185	-1.0115	80	0.3148
Self NPLC	0.55	0.81	16	No self NPLC	0.81	1.16	211	-1.2025	20	0.2432

Further Welch's unpaired T Tests were conducted on the usage of self citations. All forms of self citations, including FPC, BPC, and NPLC were tested individually, in addition to a more generalized testing of patents containing self citations. The T value for the general use of self citations found their usage to be very statistically significant. The usage of self citations does potentially add to the technological value of a biofuel patent. The usage of self FPC was found to be extremely statistically significant, while the usage of self BPC was found not to be statistically significant. The usage of self NPLC was found to be very statistically significant. However, due to the negative T values associated with the self NPLC and self BPC, higher technological values can potentially by not using these citation types.

Table 12: Descriptive Value Statistics

Statistic	Value
Minimum value	0
Maximum value	8.40
Average value	0.80
Standard deviation	1.15
Mode	0.20
Median	0.40
Total # of patents	227

technological patent value of each biofuel patents. Within Tables 13 to 19 of the Appendix, the patents are divided based on the citation type criteria associated with both the patent applicant and examiner. This approach allows for an understanding of how the citations used by both citing agents affect the distribution of patents, the corresponding technological patent values, and the usage of multidisciplinary and interdisciplinary research. In comparison, Tables 20 to 25 of the Appendix divide the patents in correlation to the citations made by the applicant only. Through these tables the affect of integrate multidisciplinary and interdisciplinary research on technological patent value, and patent distribution can be determined. The number of patents and the corresponding technological patent value is displayed in Figure 1.

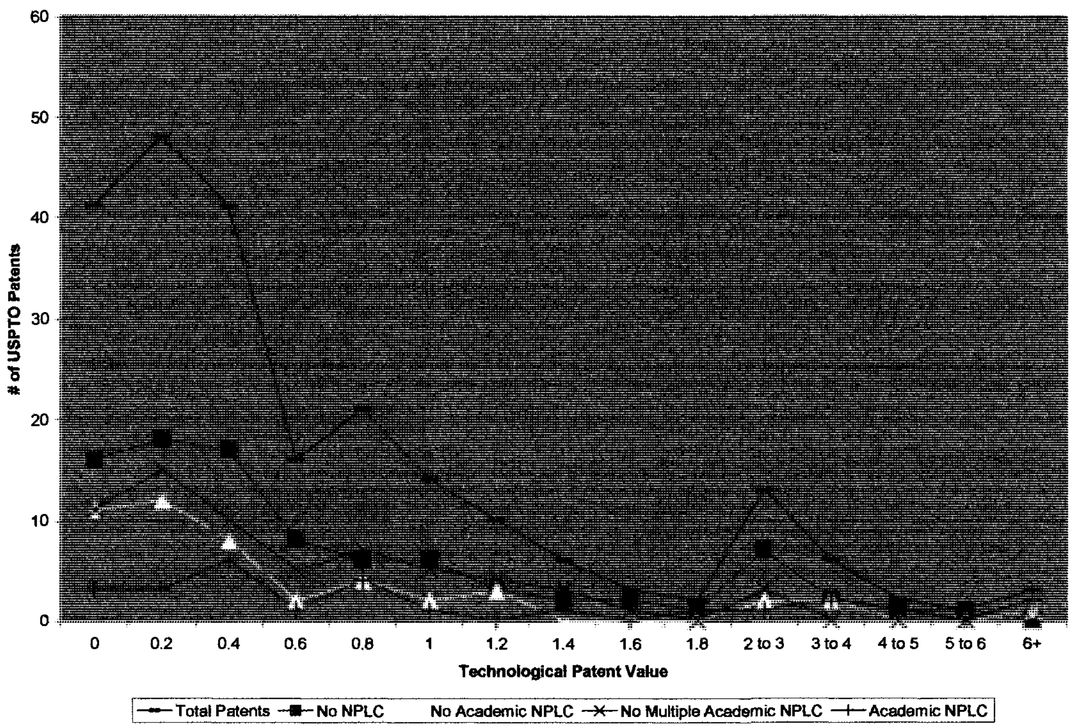

Figure 1. Technological Patent Values

4. Discussion

Due to the need to determine how multidisciplinary and interdisciplinary research enters into, and is being used within the biofuels discipline, this exploratory

4. Discussion

Due to the need to determine how multidisciplinary and interdisciplinary research enters into, and is being used within the biofuels discipline, this exploratory study looked at a number of factors beyond the affect of multidisciplinary and interdisciplinary research. Each factor was looked at as an individual step within this current study's methodology. The first step addressed where the utilized multidisciplinary and interdisciplinary research was being drawn from. The second step addressed how technical knowledge was incorporated into the patent document through FPC, BPC, NPLC, and patent assignees, and how the usage of each of the six citation types over time. The third step addressed the division and usage of the NPLC by the patent examiner and the applicant. The fourth step addressed Proposition 2 by examining the currency of the research that was being integrated into the patents through the usage of NPLC. The final step which addressed Proposition 1, evaluated the statistical relevance of NPLC, multiple academic NPLC, and self citations through the usage of Welch's unpaired T Tests.

The first step of this current study was used to determine the where the research and knowledge that is found in the patents is being drawn from. An examination of the 227 source biofuel patents revealed four categories of patents based on the types of NPLC that they contained. The two most relevant categories for this study are the patents that contain only single citations and those that contain multiple citations. Together these two categories compose 37.69% of the 227 source biofuel patents. More specifically, only 14.29% of the sampled patents contained multidisciplinary and interdisciplinary citations. The NPLC found within these two categories was revealed to be dominantly compiled from academic publications. The referenced academic publications are being drawn from six distinct disciplines. Of these six the top two most cited types of publications are biology and multidisciplinary oriented. Citations from biology oriented journals compose 40.81% of the total academic NPLC, while multidisciplinary oriented publications compose 27.15%. The usage of research from multidisciplinary sources is so significant that one of the top three most cited journals, Biotechnology and Bioengineering, is a multidisciplinary oriented publication. Based on these findings multidisciplinary and interdisciplinary research is being used in moderate amounts within biofuel patents.

The second set of results addressed to aspects, how technical knowledge was distributed across FPC, BPC, NPLC, and patent assignees, and the usage of the six citation types over time. FPC are indicative of the usage of technology or technical knowledge contained within a patent document. The 227 source biofuel patents were found to be cited by 2905 FPC between 1976 and 2008. Of the 227 source patents 95.13% were cited by at least one FPC. This indicates a high usage of the technical technology and technical knowledge contained within biofuel patents. This is further supported by the fact the average number of FPC that a patent is fairly consistent range from 11 to 15 across the four sectors of research that is represented by the patent assignees. Academically held patents possess the highest per patent average of FPC at 15.29, even though only 95.12% of academically held patents are cited by FPC. This indicates that the patents that feature FPC are cited to marginally greater extent than those patents held by other patent assignees. Academically held patents comprise the majority of self FPC at 51.94%. Such a high utilization of self citations indicates that the inventors of the academically held patents are more prone to build upon or utilize their own technologies and technical knowledge.

As with the FPC the dispersal of the average number of BPC is fairly consistent for each of the patent assignees, with the exception of publicly held patents. The average range for the average number of BPC per patent is from 7.06 to 8.81 for industry, academic, and individually held patents. For publicly held patents the average is 17.22. This indicates a greater reliance on previous technologies and technical knowledge by the inventors of the public patents. Academically held patents featured the lowest percentage of patents that featured at least one BPC with 87.80%. Industry assigned patents utilized the majority of self BPC with 38.57% of the total self BPC.

NPLC are indicative of the public or basic research that is being utilized within the patent document. The average citations per patent of NPLC are significantly lower than the averages of FPC and BPC for each patent assignee. Publicly held patents feature an average of 2.62 NPLC per patent, an average of 1.30

academic NPLC per patent, and 51.35% of these patents feature NPLC, which is the lowest amount of all patent assignees. Individual patent assignees feature the highest percentage of patents with academic NPLC, with 43.24%. Overall the majority of patents held by each patent assignee cite at least one NPLC. In looking at the usage of self NPLC citations, academically held patents utilize the most with 24.39% of academically held patents featuring at least one self NPLC, while industry held patents feature no self NPLC.

Within the patent document multidisciplinary and interdisciplinary research is primarily utilized in the form of NPLC. These citations are used by two main citing agents within the patent, the patent examiner and the patent applicant. The examiner is responsible for using the citations to define the uniqueness or innovativeness of the technology. The NPLC that are used by the applicant are integrated into the technology as prior art. The Tables in the Appendix show how multidisciplinary and interdisciplinary research in the form of multiple citations correlates to the technological patent value of each of the 227 source biofuel patents. To gain a complete picture of how the multidisciplinary and interdisciplinary research used by both the patent examiner and the applicant relate to each technological patent value, Tables 13 to 18 of the Appendix represent the combined citation types. Tables 19 to 25 of the Appendix look at a similar correlation to Tables 13 to 18; however, the division of patents is based solely on the usage of applicant citations.

The examination of how the patent applicant utilizes each of the six citation types provides insight into how the research that is integrated into the patent is being used. Between 1975 and 2005 the usage of both single and multiple citations by the patent applicant increased. This specific increase could be in response to the increased production and availability of research as the discipline emerges. A closer examination of the six citation types reveals that only four of the types have any notable increase. Both single academic and single nonacademic citations show moderate increases in usage over the examined time period. Yet, in terms of multiple citations the increases are marginal at best, and are seen in multi academic and multi mixed citations. The increase in both types of multiple citations indicates a possible increase in the availability of multidisciplinary and interdisciplinary research that is produced through academic-academic and academic-industry collaborations or industry based funding.

The distribution and usage of each of the six citations types by each citing agent within the patent document was revealed through Step 3. The patent examiner dominates in the usage of NPLC for all patent assignees, with the exception of academically held patents. With academically held patents the division of total academic NPLC is equal at 9.95% for both the patent examiner and the applicant. This indicates that within this category of patents the same amount of basic or public research is being used to define the technology, as is being integrated into technology as prior art. The applicant's usage of multiple citations, which represent multidisciplinary and interdisciplinary research, has increased over time between 1975 and 2002. However, the only real notable increases occur within the usage of multi academic and multi mixed citations, and are marginal at best.

Step 4 of the current research was designed to determine the currency of the research that is being used by the patents, thereby testing Proposition 2. Proposition 2 stated that the multidisciplinary and interdisciplinary research that is incorporated into the patents will be more current or cutting edge, and therefore will have lower citation ages. The concept behind this proposition is that multidisciplinary and interdisciplinary research possesses benefits that will either make the technology more novel or the research will reduce the amount of direct competition. As previously discussed, there are a number of benefits associated with collaborative research, which include: 1) increased opportunities for patenting or publication, 2) researcher prestige, 3) the solving of complex socio-scientific problems, 4) increased opportunities for funding or resource procurement, and 5) access to cutting edge or current research. Because of these benefits and the low amounts of multidisciplinary and interdisciplinary research within the biofuel discipline, there is a greater potential for the citing of collaborative research while it is current or cutting edge. Within the patent document current or cutting edge research is represent by a low citation age.

The results on the comparison of each of the six citation types to citation ages does not reveal any type of emphasis on current or cutting edge research. Rather there was no clustering in the distribution of each citation types across each of the citation ages. Due to this finding, there is a lack of conclusive support for Proposition 2. There are several reasons explanations that could account for this lack of support. The first factor is the type of publication that the cutting edge research is published. Higher quality publications offer such benefits greater areas of geographic distribution, more respected reputations, better quality reviews, and greater availability of articles and publications. Research that is published in these types of journals will be more assessable, and potentially perceived as being high quality. The second explanation involves the researcher's familiarity with the technical area. Researcher's that are new to the technical area or the technology are less likely to be familiar with current or cutting edge research or at least have less access to it. Therefore, the probability that researcher's who are inexperienced with the technical area, will cite large amounts of cutting edge research is quite low. The final explanation relates to the relevance of the research to the technology. Due to the fact that patented technologies are required to novel or not obvious, there may not be any current research that is relevant to the technology.

The final step in this current research was to test the statistical relevance of the usage of NPLC, multiple academic NPLC, and self citations, through the usage of Welch's unpaired T Tests. The results from the Welch's T Tests were used to address Proposition 1. As previously discussed, Proposition 1 stated that patents which utilize multidisciplinary and interdisciplinary research will have higher technological patent values than those that do not. The first T Test was run to determine the statistical relevance of using NPLC. The results of the T Test were not statistically significant, indicating that the use of NPLC does not affect the technological patent value of biofuel patents. However, the T value was found to be negative, which suggests that any affect that is caused by the usage of NPLC has on technological patent values will be negative.

The second T Test was run on the usage of multiple academic NPLC. The results of this T Test also found no statistical significance. This indicates that multidisciplinary and interdisciplinary research does not have an affect on technological patent values either. A third set of T Tests was run on the general usage of self citations, as well as each type of self citation (FPC, BPC, and NPLC).

No statistical significance was found for the usage self BPC, or self NPLC. Both self BPC and self NPLC featured negative T values. The usage of self citations, regardless of type was found to be very statistically relevant. This could be because self citations demonstrate an inventor's familiarity with the technology and the technical area. Essentially, self citations add to the inventor's prestige, and instill confidence in the patented technology. The usage of self FPC was found to be extremely statistically significant. This could be due to the fact that self FPC demonstrate a current need for the technology, and show that the inventor is building upon or utilizing the patented technology.

The question remains as to how these findings address Proposition 1. The findings of Step 1 indicate that a significant portion of the utilized NPLC are being drawn from academic multidisciplinary publications. The results of Step 2 indicate that the usage of multiple citations, which represent multidisciplinary and interdisciplinary research, has been increasing over time. These increases occur in the usage of multi academic and multi mixed citations, and are marginal increases at best. The results of Step 3 indicate that multidisciplinary and interdisciplinary research composes a mere 15.05% of the total academic NPLC. Of this 15.05% only 7.43% is integrate into the patents through applicant citations. The remaining 7.63% was used by the patent examiner to define the patented technology. Step 3 also shows that the applicant's usage of multiple citations, specifically multi academic and multi mixed is increasing over time between 1975 and 2002; however the increase is very marginal, and hardly significant. Finally, the T Test on the usage of multiple academic citations found no statistical relevance, thereby indicating the lack of effect of multidisciplinary and interdisciplinary research on technological patent values. The integration of multidisciplinary and interdisciplinary research into biofuel patents is marginal at best. Based on these combined findings, there is a lack of conclusive support for Proposition 1.

Overall, the data presented within this current study, indicates that the use of multidisciplinary and interdisciplinary research has no direct affect on the technological patent value of biofuel patents. The data also specifies that there is no prominent usage of current or cutting edge research either. The question that a rises out these findings is, why should there be a continued investment or adoption of multidisciplinary and interdisciplinary research. There are several reasons beyond the lack of an affect on technological patent value that support the continued utilization of multidisciplinary and interdisciplinary research.

The first reason is the increasing complexity of the problems that researchers are encountering and working with (Braun and Schubert, 2003). It is becoming more common that a single discipline or field is only adequately able to address a segment of a research problem. This can potentially lead to the generation of a fragmentary solution or understanding of the problem, or it can result in the excessive usage of resources as multiple disciplines address the same problem independently. Secondly, common themes, problems and methodologies between independent disciplines and fields are emerging as the production of research increases (Braun and Schubert, 2003). For example, chemistry is an independent discipline, yet many of the theories, methodologies and skills that are associated with the discipline can be applied to and are being utilized in other disciplines, such as biology, biochemistry, nanotechnology and medicine.

A third reason is that research collaboration generates a variety of opportunities, such as funding, and the application of academic research and technologies. In particular, multidisciplinary and interdisciplinary collaborations between academic and non-academic institutions generate funding opportunities through the matching of grants or funding by industry partners (Jaffe, 1989; Calderini et al., 2007). In April 2008, Husky Energy in combination with the federal and provincial governments invested a total of $4 million in the University of Manitoba's Biofuels Program, Winnipeg, Manitoba (University of Manitoba, 2008). In a similar move, the United States Department of Energy announced its contribution of $4 million in potential funding for academic institutions to develop environmentally friendly and cost-effective technologies that convert biomass into biofuels (United States Department of Energy, 2008). Beyond funding opportunities these forms of collaboration have aided academic researchers in becoming more productive in terms of publication and patent output, then their non-collaborative counterparts (Zucker and Darby, 1997). Additionally, academic-industry collaborations allow for the utilization and application of academic research. The patenting process is a good example of this type of utilization. Through patenting and technology development, academic theory, knowledge and basic research are integrated directly into innovations and technologies, which can then be used to generate further value and innovation.

5. Research Limitations and Future Research

It should be taken into consideration that as an exploratory study no conclusive findings can be drawn from the compiled data. It should be further taken into consideration that this current study presents an extremely marginalized perspective on the valuation of multidisciplinary and interdisciplinary research within the patenting process of scientific and academic research. This current study focused on the effect of two individual patent characteristics, the use of multiple academic NPLC on a single form of patent valuation, technological patent value, and the currency of multidisciplinary and interdisciplinary research. With such a finite focus, the current study does not address the complete value, benefits, and potential that multidisciplinary and interdisciplinary research brings to scientific and academic research. This study also places an emphasis on the citations used by the patent applicant, which causes the possible effects of other citing agents to be overshadowed or overlooked.

There are also several factors that should be taken into consideration when using multidisciplinary and interdisciplinary research citations. The first factor is the fact that the biofuels discipline is still in the process of emerging and developing. As a result the amount and type of available patents, technology, and scientific research is fairly limited. Accordingly, the available amounts of multidisciplinary and interdisciplinary research would be relatively low. As seen in the results of the current study, such low amounts of multidisciplinary and interdisciplinary research have no distinguishable effect on the technological patent value of biofuel patents. However, the demand for biofuels technology has continued to increase with the constant rise in fuel costs, and the public demand for alternative, green sources of energy. Evidence of this increase in demand can be seen in the biofuel discipline investments that are being made by government and industry organizations. In 2007, the Canadian federal government budgeted $2 billion over a seven year period for the development of renewable fuels (Agriculture and Food Council, 2007). In the same year planning and permitting for a $400 million bio-refinery, to be located near Innisfail, Alberta were initiated and undertaken (Scotton, 2007). As investment in the industry increases, the production of technology, patents, and scientific research will correspondingly increase. Thus, as the availability of multidisciplinary and interdisciplinary research increases, its effect on technological patent values may become more pronounced.

The second factor deals with the fact that multidisciplinary and interdisciplinary research methods take time, and effort to develop and establish. In particular, interdisciplinary research requires a cognitive change, in terms of the methodologies, skills, and practices that are used by the researcher, for the collaboration to be effective (Braun and Schubert, 2003). Such levels of cognitive change do not occur rapidly. From the findings of step 1 in the current study, it would appear that the delay generated by such a cognitive change is not a significant factor. The existence of such a delay is not likely considering that 27.15% of the academic NPLC are being drawn from multidisciplinary publications. However, multidisciplinary and interdisciplinary research only account for 15.05% of the total academic NPLC, which indicates that collaborative research within the biofuels discipline is still in the development process.

The third factor involves the relevance of the cited literature to the patented technology. United States law stipulates that all prior knowledge and art known to the applicant throughout the duration of the patent examination must be cited or else the patent will be invalidated due to potential fraud (Meyer, 2000b, p.162; Gittelman and Kogut, 2003). Applicants may therefore cite references that are only marginally relevant to the technology or innovation to avoid the risk of invalidating the patent. Such citation practices generate far more citations in each patent that is filed in the United States than other countries (Meyer, 2000b). The practice of over citation has the potential to overstate a citation type's scientific or technological relevance to a patented technology. Although the possibility of over citation was considered in the current study, it is extremely difficult to discern the relevance of each individual citation to each individual patent and technology.

As for future research there are two distinct sets of questions that arise out to the findings in the current study. The first set addresses how multidisciplinary and interdisciplinary collaborations and research projects are developed and maintained. Potential research areas include: 1) identifying the driving force(s) behind the adoption of these collaborative methods, 2) identifying the specific characteristics that are required by the institution and/or researchers to allow for successful multidisciplinary and interdisciplinary research and collaboration to occur, and 3) determining the impact of social and political ideas, beliefs and movements on the processes of research collaboration, technology development and patenting. The second set of questions that are raised deal with the factors involved in or lead to the emergence of a new techno-scientific discipline. As found in this study the discipline of biofuels significantly draws upon multidisciplinary publications, even if the numbers of cited multidisciplinary and interdisciplinary citations are only marginally used. Previous studies have indicated that multidisciplinary and interdisciplinary research has been a key factor in the development of new disciplines, such as biochemistry and biophysics. Thus, the question that arises out of these findings is: are emerging techno-scientific disciplines a result of the evolution of multidisciplinary and/or interdisciplinary practices as the literature suggests or are they a result of economic opportunity or social demand?

Further research can either address the questions that have been raised by this study or it can readdress the study using a more advanced quantitative approach. The use of a more advanced quantitative approach would reduce any potential inaccuracies generated within the basic quantitative methods that were utilized in this study. Specifically, more precise empirical information regarding the impacts of each identified variable on technological patent value, would further the understanding of multidisciplinary and interdisciplinary scientific research.

6. Conclusion

Although the exploratory approach of this current study has not produced any conclusive results about the effect of multidisciplinary and interdisciplinary research on the technology patent value of biofuel patents, it has compiled set of data that can be used for further research. Each of the steps contained within the Methodology provided insight into how multidisciplinary and interdisciplinary research is being used within the biofuels discipline. Step 1 revealed that significant portion of the total academic NPLC is being drawn from academic publications that are multidisciplinary and biology orientated. Through step 2 the results indicated that the usage of multidisciplinary and interdisciplinary research has being increasing between 1975 and 2005. However, these increases which are seen in the usage of multi academic and multi mixed citations are marginal at best. Step 2 also revealed how technical knowledge and basic research was being used through the FPC, BPC, and NPLC in correlation to each patent assignee. Step 3 showed the dominate usage of academic NPLC by the patent applicant to define the technology, and minimal amounts of multidisciplinary and interdisciplinary research that are actually being used. The lack of an emphasis or adoption of cutting edge or current multidisciplinary and interdisciplinary research was indicated through step 4. The final step, through a series of T Tests for statistical relevance, found that multidisciplinary academic research, NPLC, self BPC, and self NPLC have no significant effect on the technological patent values of biofuel patents. However, the usage of self citations, and self FPC were found to be significantly statistically relevant. Based on the findings of steps 1, 2 3 and 5 no conclusive support was found for Proposition 1. Therefore, multidisciplinary and interdisciplinary research does not appear to add to the technological patent value of biofuel patents. The findings of step 4 provide no conclusive support for Proposition 2 either. As a result there is no prominent selection and utilization of cutting edge multidisciplinary and interdisciplinary research. Even though both propositions were found to be unsupported, this research can be used in future studies of the biofuels discipline.

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Appendix

Table 13: Technological patent value – Patents with no NPLC (total citations)

Patent Number	Granting Date	Value	Total Single Citations	Total Multi Citations	# of Single Academic	# of Single Non-academic	# of Single Mixed	# of Multi Academic	# of Multi Non-academic	# of Multi Mixed
3,959,094	1976	0.40								
4,133,966	1979	6.60								
4,134,926	1979	0.00								
4,225,317	1980	1.40								
4,301,253	1981	0.40								
4,319,056	1982	0.80								
4,328,004	1982	0.20								
4,333,852	1982	0.20								
4,341,199	1982	1.00								
4,350,133	1982	0.00								
4,351,732	1982	0.80								
4,376,635	1983	0.80								
4,383,836	1983	0.00								
4,390,603	1983	0.40								
4,395,956	1983	1.20								
4,416,667	1983	0.60								
4,419,967	1983	0.20								
4,420,544	1983	0.00								
4,421,939	1983	0.00								
4,429,534	1984	0.00								
4,454,828	1984	0.60								
4,473,622	1984	1.20								
4,475,471	1984	0.20								
4,517,298	1985	0.80								
4,524,113	1985	0.00								
4,529,699	1985	0.40								
4,541,897	1985	0.40								
4,565,137	1986	2.20								
4,645,569	1987	0.40								
4,659,634	1987	0.20								
4,678,543	1987	0.00								
4,746,329	1988	1.00								
4,746,610	1988	0.00								
4,769,112	1988	0.80								
4,772,634	1988	0.00								
4,782,767	1988	0.20								
4,810,647	1989	0.40								
4,825,013	1989	0.20								
4,836,115	1989	0.20								
4,842,693	1989	0.40								
4,908,044	1990	0.00								
4,909,192	1990	0.80								
5,001,993	1991	1.20								
5,114,541	1992	0.80								
5,178,076	1993	0.40								
5,198,074	1993	0.80								
5,254,468	1993	0.00								
5,284,103	1994	0.00								
5,375,540	1994	0.20								

Table 14: Technological patent value – Patents with no NPLC continued (total citations)

Patent Number	Granting Date	Value	Total Single Citations	Total Multi Citations	# of Single Academic	# of Single Non-academic	# of Single Mixed	# of Multi Academic	# of Multi Non-academic	# of Multi Mixed
5,417,198	1995	0.40								
5,475,150	1995	0.40								
5,504,199	1996	0.00								
5,527,464	1996	1.40								
5,626,088	1997	0.60								
5,628,805	1997	0.00								
5,632,210	1997	0.20								
5,669,176	1997	2.00								
5,723,228	1998	3.20								
5,766,786	1998	0.40								
5,772,707	1998	0.00								
5,849,428	1998	0.40								
5,858,031	1999	0.60								
5,868,117	1999	1.80								
5,906,748	1999	0.00								
5,939,025	1999	0.60								
5,942,346	1999	1.20								
5,989,503	1999	0.20								
5,992,008	1999	5.00								
6,045,660	2000	0.00								
6,093,306	2000	0.20								
6,123,828	2000	0.40								
6,139,694	2000	1.40								
6,244,367	2001	1.00								
6,290,734	2001	0.20								
6,290,877	2001	0.60								
6,296,964	2001	2.40								
6,298,838	2001	0.80								
6,306,285	2001	1.40								
6,314,718	2001	0.20								
6,328,772	2001	0.00								
6,387,559	2002	3.40								
6,395,238	2002	0.20								
6,409,778	2002	0.00								
6,419,716	2002	0.20								
6,432,276	2002	0.00								
6,440,594	2002	0.80								
6,458,479	2002	1.80								
6,485,851	2002	0.60								
6,492,052	2002	1.00								
6,497,975	2002	2.40								

Table 15: Technological patent value – Patents with no academic NPLC (total citations)

Patent Number	Granting Date	Value	Total Single Citations	Total Multi Citations	# of Single Academic	# of Single Non-academic	# of Single Mixed	# of Multi Academic	# of Multi Non-academic	# of Multi Mixed
4,178,154	1979	0.00								
4,273,621	1981	1.60								
4,317,687	1982	0.20								
4,319,058	1982	0.40								
4,333,739	1982	0.20								
4,343,623	1982	0.20								
4,380,455	1983	0.20								
4,382,001	1983	0.40								
4,394,133	1983	0.00								
4,395,488	1983	0.00								
4,400,469	1983	0.20								
4,428,754	1984	1.00								
4,659,590	1987	0.40								
4,663,284	1987	0.00								
4,716,859	1988	0.40								
4,810,597	1989	0.20								
4,968,325	1990	0.00								
5,177,008	1993	0.20								
5,177,009	1993	0.20								
5,183,476	1993	0.20								
5,231,017	1993	1.40								
5,284,878	1994	0.20								
5,372,939	1994	0.00								
5,407,665	1995	1.00								
5,407,817	1995	1.60								
5,571,703	1996	1.00								
5,573,866	1996	2.40								
5,672,438	1997	0.40								
5,677,154	1997	1.20								
5,773,162	1998	7.00								
5,779,164	1998	0.80								
5,891,203	1999	1.00								
5,932,456	1999	0.20								
5,958,616	1999	2.40								
5,975,439	1999	0.40								
6,083,863	2000	0.20								
6,146,781	2000	2.40								
6,171,992	2001	1.60								
6,254,748	2001	2.40								
6,265,093	2001	3.60								
6,267,309	2001	0.60								
6,280,701	2001	0.80								
6,303,244	2001	3.00								
6,357,367	2002	2.40								
6,420,059	2002	4.20								
6,436,561	2002	2.00								

Table 16: Technological patent value – Patents with no academic multiple NPLC (total citations)

Patent Number	Granting Date	Value	Total Single Citations	Total Multi Citations	# of Single Academic	# of Single Non-academic	# of Single Mixed	# of Multi Academic	# of Multi Non-academic	# of Multi Mixed
4,041,182	1977	0.40	0	0	0	0	0	0	0	0
4,207,076	1980	1.00	2	0	2	0	0	0	0	0
4,207,077	1980	0.80	1	0	0	1	0	0	0	0
4,239,925	1980	1.00	0	0	0	0	0	0	0	0
4,242,455	1980	1.00	9	4	3	3	3	2	0	2
4,243,750	1981	0.40	7	0	4	3	0	0	0	0
4,277,635	1981	2.00	0	0	0	0	0	0	0	0
4,291,124	1981	0.00	0	0	0	0	0	0	0	0
4,297,172	1981	0.40	0	0	0	0	0	0	0	0
4,301,312	1981	0.60	2	0	2	0	0	0	0	0
4,309,359	1982	0.40	0	0	0	0	0	0	0	0
4,310,629	1982	0.40	0	0	0	0	0	0	0	0
4,321,328	1982	0.40	1	0	1	0	0	0	0	0
4,326,036	1982	0.00	2	0	2	0	0	0	0	0
4,333,740	1982	0.20	0	0	0	0	0	0	0	0
4,334,026	1982	0.20	0	0	0	0	0	0	0	0
4,347,109	1982	0.00	0	0	0	0	0	0	0	0
4,352,946	1982	0.00	0	0	0	0	0	0	0	0
4,359,534	1982	1.00	0	0	0	0	0	0	0	0
4,359,593	1982	0.20	2	0	2	0	0	0	0	0
4,360,378	1982	0.00	0	0	0	0	0	0	0	0
4,368,056	1983	0.20	0	0	0	0	0	0	0	0
4,372,822	1983	0.80	0	0	0	0	0	0	0	0
4,386,009	1983	0.80	0	0	0	0	0	0	0	0
4,407,662	1983	0.60	7	0	4	3	0	0	0	0
4,409,406	1983	0.20	0	0	0	0	0	0	0	0
4,412,845	1983	0.40	0	0	0	0	0	0	0	0
4,422,903	1983	0.40	0	0	0	0	0	0	0	0
4,442,210	1984	0.20	6	0	2	4	0	0	0	0
4,443,637	1984	0.00	2	0	1	1	0	0	0	0
4,447,534	1984	0.20	0	0	0	0	0	0	0	0
4,451,566	1984	0.20	0	0	0	0	0	0	0	0
4,455,198	1984	0.60	0	0	0	0	0	0	0	0
4,490,469	1984	0.20	0	0	0	0	0	0	0	0
4,492,808	1985	0.80	2	0	2	0	0	0	0	0
4,523,928	1985	0.40	0	0	0	0	0	0	0	0
4,556,460	1985	0.60	0	0	0	0	0	0	0	0
4,567,145	1986	0.40	0	0	0	0	0	0	0	0
4,604,352	1986	0.40	0	0	0	0	0	0	0	0
4,692,432	1987	0.20	0	0	0	0	0	0	0	0
4,812,410	1989	0.20	0	0	0	0	0	0	0	0
4,840,902	1989	0.20	0	0	0	0	0	0	0	0
4,840,903	1989	0.80	0	0	0	0	0	0	0	0
5,000,000	1991	1.20	1	0	0	1	0	0	0	0
5,028,539	1991	0.40	1	0	1	0	0	0	0	0
5,035,776	1991	0.80	2	1	1	1	0	0	0	1
5,061,497	1991	1.20	5	1	5	0	0	1	0	0
5,070,016	1991	0.40	18	0	15	3	0	0	0	0

Table 17: Technological patent value – Patents with no academic multiple NPLC continued (total citations)

Patent Number	Granting Date	Value	Total Single Citations	Total Multi Citations	# of Single Academic	# of Single Non-academic	# of Single Mixed	# of Multi Academic	# of Multi Non-academic	# of Multi Mixed
5,079,011	1992	0.80	0	0	0	0	0	0	0	0
5,135,861	1992	0.60	0	0	0	0	0	0	0	0
5,414,161	1995	0.00	27	5	15	12	0	0	2	3
5,523,177	1996	3.00	4	0	2	2	0	0	0	0
5,578,090	1996	1.40	0	0	0	0	0	0	0	0
5,578,472	1996	0.00	0	0	0	0	0	0	0	0
5,660,940	1997	1.20	0	0	0	0	0	0	0	0
5,837,506	1998	0.00	8	5	5	3	0	2	0	3
5,843,195	1998	2.60	0	0	0	0	0	0	0	0
5,976,719	1999	0.20	0	0	0	0	0	0	0	0
6,074,770	2000	0.40	6	1	3	2	1	0	0	1
6,214,484	2001	4.00	1	1	1	0	0	0	0	1
6,245,707	2001	0.40	0	0	0	0	0	0	0	0
6,355,456	2002	0.40	0	0	0	0	0	0	0	0
6,387,554	2002	1.20	0	0	0	0	0	0	0	0
6,432,378	2002	0.40	0	0	0	0	0	0	0	0
6,444,204	2002	0.00	0	0	0	0	0	0	0	0

Table 18: Technological patent value – Patents with academic multiple NPLC (total citations)

Patent Number	Granting Date	Value	Total Single Citations	Total Multi Citations	# of Single Academic	# of Single Non-academic	# of Single Mixed	# of Multi Academic	# of Multi Non-academic	# of Multi Mixed
3,941,135	1976	0.20	0	0	0	0	0	0	0	0
4,294,891	1981	0.00	7	0	4	3	0	0	0	0
4,346,241	1982	0.60	0	0	0	0	0	0	0	0
4,400,470	1983	1.00	2	0	1	1	0	0	0	0
4,560,659	1985	0.20	1	0	1	0	0	0	0	0
4,952,504	1990	0.40	6	2	5	1	0	0	0	2
5,063,156	1991	0.20	2	1	1	1	0	0	0	1
5,106,634	1992	0.80	0	0	0	0	0	0	0	0
5,173,429	1992	0.20	0	0	0	0	0	0	0	0
5,424,202	1995	0.60	38	9	30	8	0	8	0	1
5,482,846	1996	0.80	1	0	0	1	0	0	0	0
5,487,989	1996	1.00	0	0	0	0	0	0	0	0
5,554,520	1996	0.60	0	0	0	0	0	0	0	0
5,713,965	1998	1.20	0	0	0	0	0	0	0	0
5,916,780	1999	0.40	0	0	0	0	0	0	0	0
5,916,787	1999	0.00	4	0	3	1	0	0	0	0
6,015,440	2000	2.80	0	0	0	0	0	0	0	0
6,090,595	2000	0.20	0	0	0	0	0	0	0	0
6,130,076	2000	0.00	0	0	0	0	0	0	0	0
6,136,577	2000	0.00	2	1	2	0	0	1	0	0
6,146,782	2000	0.40	0	0	0	0	0	0	0	0
6,171,574	2001	8.40	0	0	0	0	0	0	0	0
6,174,501	2001	3.20	1	1	1	0	0	0	0	1
6,280,986	2001	0.20	8	0	5	3	0	0	0	0
6,398,707	2002	0.20	1	0	1	0	0	0	0	0
6,468,683	2002	0.40	0	0	0	0	0	0	0	0

Table 19: Type of BPC assignees and source patent coassignees – patents with no NPLC (based on applicant citations)

Patent Number	Granting Date	Value	Total Single Citations	Total Multi Citations	# of Single Academic	# of Single Non-academic	# of Single Mixed	# of Multi Academic	# of Multi Non-academic	# of Multi Mixed
3,941,135	1976	0.2								
3,959,094	1976	0.4								
4,133,966	1979	6.6								
4,134,926	1979	0								
4,178,154	1979	0								
4,225,317	1980	1.4								
4,301,253	1981	0.4								
4,301,312	1981	0.6								
4,310,629	1982	0.4								
4,317,687	1982	0.2								
4,319,056	1982	0.8								
4,328,004	1982	0.2								
4,333,740	1982	0.2								
4,333,852	1982	0.2								
4,341,199	1982	1								
4,350,133	1982	0								
4,351,732	1982	0.8								
4,352,946	1982	0								
4,359,534	1982	1								
4,376,635	1983	0.8								
4,383,836	1983	0								
4,386,009	1983	0.8								
4,390,603	1983	0.4								
4,395,956	1983	1.2								
4,400,469	1983	0.2								
4,400,470	1983	1								
4,416,667	1983	0.6								
4,419,967	1983	0.2								
4,420,544	1983	0								
4,421,939	1983	0								
4,422,903	1983	0.4								
4,429,534	1984	0								
4,454,828	1984	0.6								
4,473,622	1984	1.2								
4,475,471	1984	0.2								
4,490,469	1984	0.2								
4,492,808	1985	0.8								
4,517,298	1985	0.8								
4,524,113	1985	0								
4,529,699	1985	0.4								
4,541,897	1985	0.4								
4,556,460	1985	0.6								
4,565,137	1986	2.2								
4,645,569	1987	0.4								
4,659,634	1987	0.2								
4,663,284	1987	0								
4,678,543	1987	0								
4,692,432	1987	0.2								
4,716,859	1988	0.4								

Table 20: Type of BPC assignees and source patent coassignees – patents with no NPL continued (based on applicant citations)

Patent Number	Granting Date	Value	Total Single Citations	Total Multi Citations	# of Single Academic	# of Single Non-academic	# of Single Mixed	# of Multi Academic	# of Multi Non-academic	# of Multi Mixed
4,746,329	1988	1								
4,746,610	1988	0								
4,769,112	1988	0.8								
4,772,634	1988	0								
4,782,767	1988	0.2								
4,810,597	1989	0.2								
4,810,647	1989	0.4								
4,812,410	1989	0.2								
4,825,013	1989	0.2								
4,836,115	1989	0.2								
4,840,902	1989	0.2								
4,842,693	1989	0.4								
4,908,044	1990	0								
4,909,192	1990	0.8								
4,952,504	1990	0.4								
4,968,325	1990	0								
5,001,993	1991	1.2								
5,061,497	1991	1.2								
5,106,634	1992	0.8								
5,114,541	1992	0.8								
5,135,861	1992	0.6								
5,177,008	1993	0.2								
5,177,009	1993	0.2								
5,178,076	1993	0.4								
5,183,476	1993	0.2								
5,198,074	1993	0.8								
5,231,017	1993	1.4								
5,254,468	1993	0								
5,284,103	1994	0								
5,372,939	1994	0								
5,375,540	1994	0.2								
5,417,198	1995	0.4								
5,475,150	1995	0.4								
5,504,199	1996	0								
5,527,464	1996	1.4								
5,571,703	1996	1								
5,578,472	1996	0								
5,626,088	1997	0.6								
5,628,805	1997	0								
5,632,210	1997	0.2								
5,669,176	1997	2								

Table 21: Type of BPC assignees and source patent coassignees – patents with no NPLC continued (based on applicant citations)

Patent Number	Granting Date	Value	Total Single Citations	Total Multi Citations	# of Single Academic	# of Single Non-academic	# of Single Mixed	# of Multi Academic	# of Multi Non-academic	# of Multi Mixed
5,677,154	1997	1.2								
5,723,228	1998	3.2								
5,766,786	1998	0.4								
5,772,707	1998	0								
5,773,162	1998	7								
5,837,506	1998	0								
5,843,195	1998	2.6								
5,849,428	1998	0.4								
5,858,031	1999	0.6								
5,868,117	1999	1.8								
5,891,203	1999	1								
5,906,748	1999	0								
5,932,456	1999	0.2								
5,939,025	1999	0.6								
5,942,346	1999	1.2								
5,958,616	1999	2.4								
5,975,439	1999	0.4								
5,976,719	1999	0.2								
5,989,503	1999	0.2								
5,992,008	1999	5								
6,045,660	2000	0								
6,074,770	2000	0.4								
6,083,863	2000	0.2								
6,093,306	2000	0.2								
6,123,828	2000	0.4								
6,136,577	2000	0								
6,139,694	2000	1.4								
6,146,781	2000	2.4								
6,171,992	2001	1.6								
6,214,484	2001	4								
6,244,367	2001	1								
6,254,748	2001	2.4								
6,265,093	2001	3.6								
6,280,701	2001	0.8								
6,290,734	2001	0.2								
6,290,877	2001	0.6								
6,296,964	2001	2.4								
6,298,838	2001	0.8								
6,303,244	2001	3								
6,306,285	2001	1.4								
6,314,718	2001	0.2								
6,328,772	2001	0								
6,355,456	2002	0.4								
6,387,559	2002	3.4								
6,395,238	2002	0.2								
6,398,707	2002	0.2								

Table 22: Type of BPC assignees and source patent coassignees – patents with no NPLC (based on applicant citations)

Patent Number	Granting Date	Value	Total Single Citations	Total Multi Citations	# of Single Academic	# of Single Non-academic	# of Single Mixed	# of Multi Academic	# of Multi Non-academic	# of Multi Mixed
6,409,778	2002	0								
6,419,716	2002	0.2								
6,420,059	2002	4.2								
6,432,276	2002	0								
6,432,378	2002	0.4								
6,436,561	2002	2								
6,440,594	2002	0.8								
6,458,479	2002	1.8								
6,468,683	2002	0.4								
6,485,851	2002	0.6								
6,492,052	2002	1								
6,497,975	2002	2.4								

Table 23: Type of BPC assignees and source patent coassignees – patents with no academic NPLC (based on applicant citations)

Patent Number	Granting Date	Value	Total Single Citations	Total Multi Citations	# of Single Academic	# of Single Non-academic	# of Single Mixed	# of Multi Academic	# of Multi Non-academic	# of Multi Mixed
4,041,182	1977	0.4								
4,273,621	1981	1.6								
4,309,359	1982	0.4								
4,319,058	1982	0.4								
4,333,739	1982	0.2								
4,343,623	1982	0.2								
4,346,241	1982	0.6								
4,347,109	1982	0								
4,360,378	1982	0								
4,380,455	1983	0.2								
4,382,001	1983	0.4								
4,394,133	1983	0								
4,395,488	1983	0								
4,409,406	1983	0.2								
4,428,754	1984	1								
4,659,590	1987	0.4								
5,035,776	1991	0.8								
5,079,011	1992	0.8								
5,284,878	1994	0.2								
5,407,665	1995	1								
5,407,817	1995	1.6								
5,414,161	1995	0								
5,573,866	1996	2.4								
5,578,090	1996	1.4								
5,672,438	1997	0.4								
5,779,164	1998	0.8								
6,090,595	2000	0.2								
6,174,501	2001	3.2								
6,267,309	2001	0.6								
6,280,986	2001	0.2								
6,357,367	2002	2.4								

Table 24: Type of BPC assignees and source patent coassignees – patents with no academic multiple NPLC (based on applicant citations)

Patent Number	Granting Date	Value	Total Single Citations	Total Multi Citations	# of Single Academic	# of Single Non-academic	# of Single Mixed	# of Multi Academic	# of Multi Non-academic	# of Multi Mixed
6,387,554	2002	1.2	2	0	1	1	0	0	0	0
4,207,076	1980	1	1	0	0	1	0	0	0	0
4,207,077	1980	0.8	1	0	0	1	0	0	0	0
4,239,925	1980	1	1	0	0	1	0	0	0	0
4,242,455	1980	1	2	0	2	0	0	0	0	0
4,243,750	1981	0.4	3	0	2	1	0	0	0	0
4,277,635	1981	2	1	0	1	0	0	0	0	0
4,291,124	1981	0	2	0	2	0	0	0	0	0
4,297,172	1981	0.4	3	0	3	0	0	0	0	0
4,321,328	1982	0.4	2	0	2	0	0	0	0	0
4,326,036	1982	0	4	0	0	4	0	0	0	0
4,334,026	1982	0.2	2	0	2	0	0	0	0	0
4,359,593	1982	0.2	1	0	0	1	0	0	0	0
4,368,056	1983	0.2	1	0	1	0	0	0	0	0
4,372,822	1983	0.8	3	0	0	3	0	0	0	0
4,407,662	1983	0.6	1	0	1	0	0	0	0	0
4,412,845	1983	0.4	1	0	1	0	0	0	0	0
4,442,210	1984	0.2	1	0	0	1	0	0	0	0
4,443,637	1984	0	1	0	0	1	0	0	0	0
4,447,534	1984	0.2	2	0	1	1	0	0	0	0
4,451,566	1984	0.2	1	0	1	0	0	0	0	0
4,455,198	1984	0.6	2	0	0	2	0	0	0	0
4,523,928	1985	0.4	1	0	0	1	0	0	0	0
4,567,145	1986	0.4	2	0	2	0	0	0	0	0
4,604,352	1986	0.4	4	0	4	0	0	0	0	0
4,840,903	1989	0.8	2	0	0	2	0	0	0	0
5,000,000	1991	1.2	6	0	5	1	0	0	0	0
5,028,539	1991	0.4	1	0	1	0	0	0	0	0
5,070,016	1991	0.4	1	0	1	0	0	0	0	0
5,173,429	1992	0.2	3	0	3	0	0	0	0	0
5,523,177	1996	3	1	0	0	1	0	0	0	0
5,660,940	1997	1.2	4	0	2	2	0	0	0	0
6,015,440	2000	2.8	1	0	1	0	0	0	0	0
6,146,782	2000	0.4	1	0	1	0	0	0	0	0
6,245,707	2001	0.4	3	0	2	1	0	0	0	0
6,444,204	2002	0	1	0	1	0	0	0	0	0

Table 25: Type of BPC assignees and source patent coassignees – patents with academic multiple NPLC (based on applicant citations)

Patent Number	Granting Date	Value	Total Single Citations	Total Multi Citations	# of Single Academic	# of Single Non-academic	# of Single Mixed	# of Multi Academic	# of Multi Non-academic	# of Multi Mixed
4,294,891	1981	0	7	4	3	3	1	2	0	2
4,560,659	1985	0.2	2	1	0	2	0	1	0	0
5,063,156	1991	0.2	6	2	5	1	0	0	0	2
5,424,202	1995	0.6	7	3	5	2	0	0	1	2
5,482,846	1996	0.8	20	5	16	4	0	4	0	1
5,487,989	1996	1	21	7	15	6	0	0	1	6
5,554,520	1996	0.6	14	3	9	5	0	0	1	2
5,713,965	1998	1.2	7	4	4	3	0	1	0	3
5,916,780	1999	0.4	1	1	1	0	0	0	0	1
5,916,787	1999	0	17	5	14	3	0	3	0	2
6,130,076	2000	0	11	3	9	2	0	1	0	2
6,171,574	2001	8.4	7	2	5	2	0	1	0	1