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University-to-Industry Technology Transfer: Organizational Aspects

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Vollständiger Abdruck der von der Fakultät TUM School of Management der Technischen Universität München zur Erlangung des akademischen Grades eines

Doktors der Wirtschaftswissenschaften (Dr. rer. pol.)

genehmigten Dissertation.

Vorsitzender:	Univ.-Prof. Dr. M. Grunow
Prüfer der Dissertation:	1. Univ.-Prof. Dr. J. Henkel
	2. Univ.-Prof. Dr. I. M. Welpe

Die Dissertation wurde am 25.07.2013 bei der Technischen Universität München eingereicht und durch die Fakultät TUM School of Management am 15.10.2013 angenommen.

Danksagung

An dieser Stelle möchte ich die Gelegenheit nutzen, mich bei einigen Personen zu bedanken, ohne die diese Dissertation nicht in gleicher Qualität möglich gewesen wäre.

Mein größter Dank geht an meinen Doktorvater, Joachim Henkel. Durch seine hervorragende Betreuung, seinen großen Erfahrungsschatz und seine Begeisterung für die Forschung unterstützte er mich während des gesamten Promotionsprojektes. Er hatte immer ein offenes Ohr und stand mir mit Rat und Tat zur Seite. Zahlreiche Diskussionen und sein wertvolles Feedback halfen mir, mein Ziel nicht aus den Augen zu verlieren. Ebenfalls bedanken möchte ich mich bei meiner Zweitgutachterin Isabell Welpe und bei Martin Grunow für den Vorsitz der Prüfungskommission.

Ein ganz besonderer Dank gilt meinen Koautoren Guido Buenstorf, Bruno van Pottelsberghe de la Potterie, Gaétan de Rassenfosse, Dominik Heinisch und Annelies Wastyn. Für die Unterstützung bei der Programmierung möchte ich mich bei Xiao Chen, Franziska Haunholder, Edgar Müller, Alejandra Rodriguez und Maximilian Szengel bedanken. Auch meinen zahlreichen Interviewpartnern gilt dieser. Für die Unterstützung, insbesondere auf den letzten Metern, möchte ich bei Caroline Schnitzer bedanken.

Meine Auslandsaufenthalte in Australien und Belgien wurden erst durch Beth Webster und Bruno van Pottelsberghe de la Potterie ermöglicht, hiermit möchte ich mich herzlich dafür bedanken. In diesem Zusammenhang möchte ich mich auch bei der European Science Foundation bedanken, durch die ich eine finanzielle Unterstützung für den Aufenthalt in Brüssel und für Konferenzbesuche erhielt.

Einen ganz persönlichen Dank für die gemeinsame Zeit am Lehrstuhl möchte ich meinen aktuellen und ehemaligen Kolleginnen und Kollegen am Dr. Theo Schöller-Stiftungslehrstuhl für Technologie- und Innovationsmanagement aussprechen: Jörn Block, Rainer Filitz, Timo Fischer, Markus Hagenmaier, Daniel Hoenig, Alexander Hofmann, Florian Jell, Katharina Kagerer, Robert Lüttke, Christina Raasch, Tim Schweißfurth, Manuel Sojer, Annika Stiegler, Josef Waltl, Hans Zischka sowie Evelin Winands als gute Seele des Lehrstuhls. Zahlreiche fachliche Diskussionen und eine tolle Teamatmosphäre haben die Zeit am Lehrstuhl zu einer unvergessenen gemacht.

Abschließend möchte ich mich von ganzem Herzen bei Wolfgang für seine Liebe, seine Unterstützung, seine Geduld und seinen unendlichen Optimismus bedanken. Auch in schwierigen Zeiten war er stets parat und hat mir den nötigen Rückhalt gegeben. Ohne ihn wäre diese Arbeit so nicht möglich gewesen.

Ich bedanke mich herzlich bei meinen Eltern, meiner Schwester und meinem Schwager für ihre anhaltende Unterstützung. Meine Eltern standen mir immer bei und haben mir beigebracht, neugierig zu bleiben. Durch ihre Förderung und ihr Vertrauen in meine Fähigkeiten haben sie mir stets den Rücken gestärkt. Somit haben sie die Grundlage für diese Promotion geschaffen. Diese Arbeit ist für euch.

Anja Schön

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List of abbreviations

EPO	European Patent Office
GPTO	German Patent and Trademark Office
IP	Intellectual property
MIT	Massachusetts Institute of Technology
OECD	Organisation for Economic Co-operation and Development
R&D	Research and Development
TTA	Technology transfer alliance
TTB	Technologietransferbüro
TTO	Technology transfer office
U.S.	United States
USA	Vereinigte Staaten von Amerika
USPTO	United States Patent and Trademark Office

Publication and submission record

The present work is submitted as cumulative thesis and is based on four publications:

1. Schoen, A., van Pottelsberghe de la Potterie, B., Henkel, J. (in press): Governance typology of universities' technology transfer processes. *The Journal of Technology Transfer*. doi: http://dx.doi.org/10.1007/s10961-012-9289-0.
2. Schoen, A., Heinisch, D., Buenstorf, G. (2013): *Playing the 'Name Game' to identify university patents in Germany*. Working Paper. Available at SSRN: http://ssrn.com/abstract=2289218.
3. de Rassenfosse, G., Schoen, A., Wastyn, A. (in press): Selection bias in innovation studies: A simple test. *Technological Forecasting and Social Change*. doi: http://dx.doi.org/10.1016/j.techfore.2013.02.012.
4. Schoen, A., Buenstorf, G. (forthcoming): When do universities own their patents? An explorative study of patent characteristics and organizational determinants in Germany. Accepted for publication in *Industry and Innovation*.

Zusammenfassung

Der Technologietransfer aus Universitäten in die Industrie zählt in einer modernen Wirtschaft, neben Forschung und Lehre, zu den vorrangigen Aufgaben von Universitäten. Die damit einhergehende Veränderung der Rolle von Universitäten stellt diese vor neue Herausforderungen. Beispielsweise ist das professionelle Management von geistigem Eigentum für die Mehrzahl der Universitäten (insbesondere in Europa) eine bisher ungekannte Aufgabe. Um dieser gerecht zu werden, wurden Technologietransferbüros (TTBs) als Intermediäre zwischen Universität und Industrie gegründet.

Wissenschaftler begannen den Technologietransfer aus Universitäten in die Privatwirtschaft zunächst in den USA und dann in Europa zu untersuchen. Hierbei liegen die Forschungsschwerpunkte unter anderem in der Untersuchung der Leistungsfähigkeit von TTBs sowie in der Untersuchung von universitären Patentaktivitäten. Allerdings blieben organisatorische Unterschiede als Einflussfaktoren in beiden Feldern weitestgehend unberücksichtigt. Kenntnis über diese Faktoren ist für die Wissenschaft, die Universitätsleitung sowie politische Entscheidungsträger wichtig, um interinstitutionelle Unterschiede und den Einfluss jüngster Gesetzesänderungen besser zu verstehen.

Die vorliegende Dissertation leistet durch die Untersuchung ausgewählter Organisationsdeterminanten im Technologietransferprozess mit Fokus auf Patentaktivitäten einen Beitrag zur Schließung dieser Lücke. Des Weiteren werden methodische Probleme diskutiert, die einerseits mit der Untersuchung akademischer Patentaktivitäten sowie andererseits mit der Messung der Innovationsleistung einer Organisation durch die Anzahl der angemeldeten Patente einhergehen. Diese Arbeit wurde als publikationsbasierte Dissertation eingereicht und basiert auf vier Publikationen.

Die erste Studie „Governance typology of universities’ technology transfer processes“ – gemeinsam verfasst mit Bruno van Pottelsberghe de la Potterie und Joachim Henkel (publiziert im The Journal of Technology Transfer) – analysiert Governance Strukturen von TTBs in Europa. Obwohl das Interesse an universitärem Technologietransfer weiter zunimmt, ist der Kenntnisstand hinsichtlich der Governance Struktur als ein wichtiger Einflussfaktor gering. Die wenigen existierenden Studien konzentrieren sich auf die USA und betrachten meist nur eine Dimension der Governance Struktur. Ein besseres Verständnis dieser ist für die Universitätsleitung –

die für die Organisation des Technologietransfers verantwortlich ist – sowie auch für Wissenschaftler – die Unterschiede im Technologietransfer untersuchen möchten – relevant. Die Studie leistet einen Beitrag zur bestehenden Forschung in zweierlei Hinsicht. Erstens wird die Vielfalt der vorherrschenden Modelle auf theoretischer Basis analysiert und eine konzeptionelle Grundlage für die Organisation des Technologietransfers zur Verfügung gestellt. Basierend auf vier strukturellen Variablen – Grad an Fachspezialisierung, Grad an Aufgabenspezialisierung, Grad an Autonomie und Grad an Exklusivität – wird eine Typologie abgeleitet, die vier Haupttypen der Governance Struktur von TTBs umfasst: (1) das klassische TTB, (2) das autonome TTB, (3) die disziplinübergreifende Technologietransferallianz, (4) die disziplinspezialisierte Technologietransferallianz. Zweitens werden anhand von 16 Fallstudien die Vor- und Nachteile der vier Haupttypen diskutiert. Diese Diskussion liefert einen empirischen Überblick darüber, wie die Governance Struktur den Technologietransferprozess und insbesondere das Management des geistigen Eigentums beeinflusst.

Die zweite Studie „Playing the ‘Name Game’ to identify university patents in Germany“ – gemeinsam verfasst mit Dominik Heinisch und Guido Buenstorf (Arbeitspapier, eingereicht bei Scientometrics) – präsentiert einen neuen Ansatz zur Identifizierung akademischer Patente, die nicht notwendigerweise von der Universität angemeldet wurden. Die Identifizierung dieser Patente ist sowohl für die Messung der universitären Patentaktivitäten sowie auch für die Beurteilung der jüngsten Gesetzesänderungen und politischen Initiativen zur Verbesserung des Technologietransfers aus Universitäten von Bedeutung. Jedoch ist die hierzu notwendige Identifizierung von Individuen in großen Datenbanken mit verschiedenen Herausforderungen behaftet und bestehende Ansätze lassen sich nicht ohne gravierende Einschränkungen auf Deutschland übertragen. Daher wurden existierende Ansätze angepasst und die daraus resultierenden Ergebnisse mit Ergebnissen aus vorhandenen Ansätzen verglichen (wie zum Beispiel die Verwendung des Professorentitels zur Identifizierung akademischer Patente). Diese Studie liefert Erkenntnisse für zukünftige Arbeiten mit Patentdaten auf Individualebene, welche auch außerhalb des hier behandelten Feldes angewendet werden können. Des Weiteren wird die Erkenntnis aus vorangegangenen Studien untermauert, dass die alleinige Betrachtung der universitätseigenen Patente für die Bewertung der Rolle akademischer Patentierung in Europa unzureichend ist.

Die dritte Studie „Selection bias in innovation studies: A simple test“ (publiziert im Journal Technological Forecasting and Social Change) wurde gemeinsam mit Gaétan de Rassenfosse (Erstautor) und Annelies Wastyn verfasst. Der Artikel diskutiert Selektionsverzerrungen in Innovationsstudien, die durch das Zählen von Patentanmeldungen an einem Patentamt (beispielsweise am Europäischen Patentamt) auftreten können. Ein einfach zu implementierender Test, um potentielle Selektionsverzerrungen zu untersuchen, wird vorgestellt und diskutiert. Zwei Datensätze, die einerseits alle Patentanmeldungen belgischer Unternehmen und andererseits alle Patentanmeldungen deutscher Universitäten umfassen, wurden herangezogen, um die Problematik empirisch darzulegen. Es wird empfohlen, Ergebnisse, die auf dem Zählen von Patentanmeldungen an einem Patentamt beruhen, kritisch zu interpretieren. Die gewonnenen Erkenntnisse können auch auf andere empirische Szenarien übertragen werden.

Die vierte Studie „When do universities own their patents? An explorative study of patent characteristics and organizational determinants in Germany“ (zur Publikation im Journal Industry and Innovation angenommen) – gemeinsam verfasst mit Guido Buenstorf – nutzt einen neuen Datensatz für akademische Patente, um zu untersuchen, wie Patent- sowie Organisationsvariablen mit der Eigentümerstruktur der Patente zusammenhängen. Ein besseres Verständnis dieses Zusammenhanges ist wichtig, um Unterschiede im universitären Technologietransferprozess zu verstehen und den Einfluss von jüngsten Gesetzesänderungen zu evaluieren. Bisherige Forschung analysierte Unterschiede zwischen universitätseigenen (*university-owned*) Patenten und Patenten, die aus der Universität stammen, allerdings nicht von dieser angemeldet wurden (*university-invented but not -owned*), sowie zwischen Universitäts- und Industriepatenten. Jedoch blieb die Frage unbeantwortet, ob sich Universitäten mit unterschiedlichen organisatorischen Identitäten und Leistungsstärken in der Eigentümerstruktur der Patente unterscheiden. Dieser Frage wurde in der vorliegenden Studie nachgegangen. Hierfür wurden 1.167 akademische Patente aus 61 deutschen Universitäten, die in 2006 oder 2007 angemeldet wurden, untersucht. Es zeigt sich, dass circa 60% aller akademischen Patente von der Universität angemeldet wurden und somit als *university-owned* zu bezeichnen sind. Dies wiederum deutet darauf hin, dass Universitäten die Abschaffung des Hochschullehrerprivilegs in 2002 schnell adaptierten. Darüber hinaus zeigt sich, dass sich Universitäten und technische Universitäten nicht hinsichtlich der Wahrscheinlichkeit unterscheiden, Patente selbst anzumelden. Allerdings ergab die empirische Analyse, dass sich Patenteigenschaften und Leistungen in anderen Bereichen unterschiedlich auf die Eigentümerstruktur auswirken.

Abstract

University-to-industry technology transfer has become a primary mission of universities (in addition to research and teaching) in the modern economy; the concomitant change in its roles has introduced new challenges for research institutions. For example, in the majority of universities (particularly in Europe), professional intellectual property (IP) management is an unprecedented responsibility. In response, technology transfer offices (TTOs) were established as intermediaries between the university and industry.

Scholars began to study university-to-industry technology transfer first in the United States and more recently in Europe. Major research fields are devoted to university TTO performance and academic patenting. However, the differences in university organizational determinants are largely neglected in both fields. Understanding such determinants is important for scholars, university managers and policy-makers to better discern inter-institutional differences and assess the impact of recent legal reforms.

This thesis addresses this gap by investigating selected university organizational dimensions in the technology transfer process focused on patent-related activities. Moreover, methodological issues related to studying academic patents and generally to studying organizations' innovative output through the number of patents applied for are discussed. This thesis is submitted as a cumulative thesis and is based on four publications.

The first study "Governance typology of universities' technology transfer processes" co-authored with Bruno van Pottelsberghe de la Potterie and Joachim Henkel (published in the Journal of Technology Transfer) analyzes the governance structure of TTOs in Europe. Despite the growing interest in technology transfer from universities, little is known on the governance structure as an organizational determinant. The few existing studies focus on the U.S. and primarily consider only one dimension of the governance structure. Understanding the governance structure is important for university management in organizing the technology transfer and for scholars comparing university technology transfer of TTOs. This article contributes to the existing literature in two ways. First, the authors theoretically analyze the diversity of the prevailing organizational models and provide a conceptual basis for organizing university technology transfer activities. Based on four structural variables – degree of discipline specialization, degree of task specialization, level of autonomy and degree of

exclusivity – the authors derived a typology with four primary types of governance structures for TTOs: (1) classical technology transfer office, (2) autonomous technology transfer office, (3) discipline-integrated technology transfer alliance, and (4) discipline-specialized technology transfer alliance. Second, the advantages and disadvantages for the four types are discussed using 16 case studies from six European countries; this discussion provides an empirical overview on how the governance structure affects the technology transfer process, particularly IP management.

The second study "Playing the 'Name Game' to identify university patents in Germany" co-authored with Dominik Heinisch and Guido Buenstorf (working paper, submitted to Scientometrics) presents a new approach for using databases to identify academic patents, which are not necessarily owned by universities. Identifying such patents is important for measuring the patent activities of universities and faculty as well as assessing legal reforms and policy initiatives aimed at fostering university-to-industry technology transfer. However, such identification is not straightforward because individuals are notoriously difficult to find in large databases. Existing approaches cannot be transferred to Germany without serious limitations. Thus, adjusted techniques were used for Germany, and the results were compared with existing approaches (e.g., using the professor title to identify academic patents). This study will inform future work on inventor data, which is applicable beyond academic patents. Moreover, the study corroborates previous studies on academic patenting in Europe in that using only patents owned by universities is insufficient for evaluating the role of academic patenting in Europe.

The third study is "Selection bias in innovation studies: A simple test" (published in Technological Forecasting and Social Change) co-authored with Gaétan de Rassenfosse (leading author) and Annelies Wastyn. This article discusses selection bias in innovation studies from counting patent applications at a single office (e.g., the European Patent Office (EPO)). This article proposes an easily implemented methodology to investigate potential selection bias. Two datasets with all of the patent applications from Belgian firms and German universities were used to empirically demonstrate that counting patent applications in a single office affects estimates for invention productivity due to selection bias. This study suggests that estimates based on counting patent applications in a single office should be interpreted with caution. The results are also relevant beyond invention productivity.

The fourth study – "When do universities own their patents? An explorative study of patent characteristics and organizational determinants in Germany" (accepted for publication in Industry and Innovation) co-authored with Guido Buenstorf – uses a novel dataset for academic patents to analyze how patent and organizational variables relate to ownership patterns. Understanding such determinants is important for better discerning the differences in university technology transfer processes and assessing the impact of recent legal reforms. Previous research began analyzing the differences between university-owned and university-invented (but not -owned) patents as well as between university and industry patents. However, the question whether universities with different organizational identities and performance levels vary in their ownership patterns remained unanswered. This article addresses this gap by analyzing 1,167 patents invented by professors in 61 German universities and filed in 2006 or 2007. The study finds that 60% of academic patents are university-owned, which indicates that universities rapidly adapted to abolishment of the professors' privilege in 2002. Additionally, a major finding is that technical universities and general research universities do not differ in likelihood of patent ownership; however, the authors observed differences in how patent characteristics and performance in other realms affect ownership patterns.

1 University-to-industry technology transfer – an overview

1.1 Introduction

Universities around the world have undergone substantial changes over the past few decades. Such changes have been particularly pronounced in university-industry relationships such that university technology transfer to the private sector is considered a “third mission” (Etzkowitz & Leydesdorff, 2000) in addition to teaching and research. Drivers for this development range from recognizing the importance of knowledge in economic development and innovation over financial constraints on academic research to public initiatives that promote university-to-industry technology transfer.

Increasing interest in commercializing publicly funded research by scholars, university managers, and policy makers has led to a rapidly growing area of research. However, scholars have primarily been focused on the U.S.; also organizational dimensions, such as the governance structure of technology transfer offices (TTOs) and organizational differences in university intellectual property (IP) management, have largely been neglected in such discussions. Understanding the differences in organizational dimensions is important for more efficient, effective technology transfer management by universities, assessing recent legislative reforms, and designing suitable initiatives to foster university-to-industry technology transfer by policy-makers. This cumulative thesis addresses the gap by analyzing the governance structures of European TTOs (Study 1, cf. Chapter 2) and organizational-level determinants for university patent ownership (Study 4, cf. Chapter 5). This author discusses in detail an approach to identify patents originating from academic research (Study 2, cf. Chapter 3). Moreover, this discussion addresses measuring the innovative output from organizations by counting patent applications from a single office (e.g., the European Patent Office (EPO)) and the resulting potential selection bias (Study 3, Chapter 4).

This chapter analyzes factors that drive the changing role of universities and the concomitant changes in university organizational structure (e.g., TTO establishment and IP management). Section 1.2 discusses the role of universities in a knowledge-based economy. Section 1.3 summarizes the legislative initiatives to foster university-to-industry technology transfer in the United States and Europe. Section 1.4 discusses the emergence of TTOs as intermediaries in the transfer process and empirical results from an investigation on TTO performance. The section closes by introducing the paper “Governance typology of universities’ technology transfer processes” (Study 1). Section

1.5 is devoted to university patenting and introducing the motivation underlying the article "When do universities own their patents? An explorative study of patent characteristics and organizational-determinants in Germany" (Study 4). Moreover, this section briefly discusses methodologies issues concomitant with innovation studies (Study 3) and academic patenting in particular (Study 2). The final section includes a summary and conclusion.

1.2 Universities in a knowledge-based economy

1.2.1 The knowledge-based economy

Recently, the term knowledge-based has been widely used by academics and politicians to characterize today's economy. For example, in the European Commission's Lisbon Strategy in 2000, European leaders set the strategic goal "to become the most competitive and dynamic knowledge-based economy in the world capable of sustainable economic growth with more and better jobs and greater social cohesion" (Kok, 2004, p. 6). However, recognizing the importance of knowledge for economic growth and society is not new and dates back to seminal works by Peter Drucker (1959), Fritz Machlup (1962) and Daniel Bell (1973).[1]

The concept of a knowledge-based economy as it is used today was first introduced by Foray & Lundvall (1996) and further developed by academics as well as politicians. The Organisation for Economic Co-operation and Development (OECD) played a major role in such development and extensively promoted this concept.[2] However, knowledge-based economy is still very poorly defined and "(…) it must be said, that there is no coherent definition, let alone theoretical concept, of this term: it is at best a widely used metaphor, rather than a clear concept" (Smith, 2002, p. 6). Powell & Snellman (2004) perceive the key component of this concept as knowledge, not natural resources or physical input. According to OECD (1996, p. 3), knowledge-based economies "(…) are directly based on the production, distribution and use of knowledge and information. This is reflected in the trend in OECD economies towards growth in high-technology investments, high-technology industries, more highly-skilled labour and associated productivity gains". To conclude, even without a clear definition for knowledge-based economy and without claiming that the concept is new, this metaphor

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1 Implicitly, the concept of a knowledge-based economy was discussed by Karl Marx (1969), Max Weber (1972), and Joseph Schumpeter (1939, 1993).

2 For a critical discussion on the role of the OECD in disseminating this concept, see Godin (2006).

facilitates a consensus on the importance of knowledge and innovation for long-term economic growth.

This notion is also reflected in economic theories (Sabau, 2010). Though the neoclassical economic growth function encompassed capital and labor (Solow, 1956), subsequent research, particularly the new growth theory, added technology and science to such consideration (e.g., Romer, 1986, 1990; Grossman & Helpman, 1993; Conceição et al., 1998; Godin, 2004).

The relevance of knowledge also has been analyzed empirically. For example, Fritz Machlup (1962) estimates the importance of knowledge to the United States' industry: His study reveals that the knowledge industry accounted for 29% of the gross national product in 1958. The university as a "knowledge factory" is perceived as the nexus for producing knowledge (Machlup, 1982). Similarly, Williams (1986) states that publicly funded research has direct and indirect positive effects on technological processes and economic performance. Based on such findings, interest in the university (and publically funded research generally) contribution to economic growth increased, and a large body of scholarly literature emerged which analyzed the benefits of publicly funded research for the economy (Salter & Martin, 2001).

1.2.2 The benefits of academic research

Seminal papers on the relationship between academic research and industrial innovations by Edwin Mansfield were early contributions to this research field. Based on a survey of research and development (R&D) managers in 76 U.S. firms from seven industries, Mansfield (1991) found that 11% of new products and 9% of new processes could have not been developed within a particular time-frame without input from academic research. The social rate of return is estimated at 28%. In his subsequent study, Mansfield (1997) confirmed the previous result: R&D managers stated that on average 15% of products and 11% of processes would have not been developed without substantial delay absent academic research.[3] The studies by Mansfield (1991, 1997) were replicated in Germany by Beise & Stahl (1999), who surveyed 2,300 companies. They found that 9% of firms with at least one product or process innovation between 1993 and 1996 introduced innovations that would not have been developed absent public research. Based on an inventor survey in the Netherlands, Tijssen (2002)

[3] In his first study, Mansfield surveyed 76 U.S. firms in seven manufacturing industries (information processing, electrical equipment, chemicals, instruments, drugs, metals, and oil). His follow up study included 77 U.S. firms. The machinery industry substituted for the oil industry (Mansfield, 1991, 1997).

concluded that approximately 20% of patented technologies that became innovations were (partially) based on public research. Based on the Carnegie Mellon Survey, Cohen et al. (2002) more recently confirmed that publicly funded research in the United States plays an important role in industrial innovation.

Narin et al. (1997) used a different approach and examined the link between U.S. patents and scientific research papers from 1993–1994. They found that the majority (73%) of papers cited in industrial U.S. patent applications were authored by scholars affiliated with public research organizations. They concluded that technological progress in the U.S. industry is strongly supported by public science.[4] McMillan et al. (2000) support Narin et al.'s results (1997) and found a stronger link between U.S. inventions and public science for the biotechnology industry. Similarly, Jaffe (1989) estimated that university research has a significant effect on corporate patents at the state-level. Verbeek et al. (2002) corroborated the result that the intensity of the industry-science link depends on scientific and technological fields.

Other researchers have concentrated on analyzing the benefits of (1) skilled graduate and scientist migration in the private sector (e.g., Gibbons & Johnston, 1974; Martin & Irvine, 1981; Zellner, 2003); (2) new instruments and methodologies (e.g., Rosenberg, 1992); (3) creating networks and social interactions (e.g., de Solla Price, 1984; Callon, 1994); (4) increasing the technological problem-solving capacity (e.g., Klevorick et al., 1995); or (6) creating new firms (e.g., Zucker et al., 1998; Malo, 2009) for economic growth.

In summary, empirical research has demonstrated that publicly funded research plays an active role in creating value for innovation and economic growth. In the following, the focus is on universities as the provider for knowledge and technology. A discussion on public research organizations is beyond the scope of this thesis.

1.2.3 Universities in the Triple Helix model

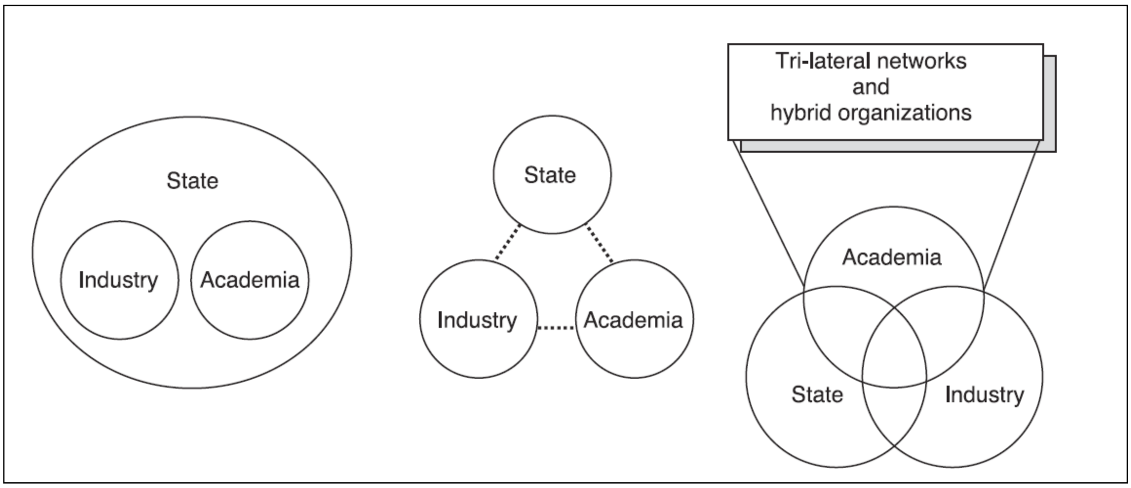
Recognition of and empirical evidence for the high impact of publicly funded research on economic propensity in a knowledge-based economy have been accompanied by tighter budget constraints on academic institutions. Financial constraints forced universities to increasingly search for alternative sources of funding (e.g., Henderson et al., 1998; Geuna, 2001; Thursby & Thursby, 2002; Mowery & Sampat, 2005; Bercovitz & Feldman, 2008). Moreover, policy makers considered

[4] Using non-patent literature references as a proxy for the dependence of the invention on science is perceived as critical by other researchers (e.g., Tijssen, 2002).

actions to foster interactions between universities and industries (cf. Section 1.3) (e.g., Shane, 2004). These closely interlinked developments resulted in a shift of universities' role within the economic system.

Henry Etzkowitz and colleagues described this evolution for universities in the Triple Helix framework (Etzkowitz & Leydesdorff, 1999, 2000; Etzkowitz et al., 2000; Etzkowitz, 2003, 2004, 2008; Etzkowitz et al., 2008). In this analytic model, the university is perceived as an "(…) influential actor and equal partner in a "Triple Helix" of university-industry-government relations" (Etzkowitz, 2003, p. 295). This transformation originated through either an etatistic or laissez-faire model (cf. Figure 1) (Etzkowitz & Leydesdorff, 2000; Etzkowitz, 2003; Etzkowitz et al., 2008).

Figure 1: From etatistic and laissez-faire models to the Triple Helix model



Source: Etzkowitz (2003, p. 302)

The etatistic model describes conditions wherein the government is the dominant sphere that encompasses industry and academia; this was the model used in the former Soviet Union. Most western countries used the latter model, which describes conditions wherein the three spheres are independent and each sphere has distinct tasks. Both models transform into the Triple Helix model. The core of this new model is that the three spheres are intertwined and each sphere undertakes tasks traditionally performed by another sphere but preserves its core missions. Tri-lateral networks and hybrid organizations combining tasks of at least two spheres emerged.

The second academic revolution included an additional integration of economic and social development into universities' tasks (Etzkowitz, 2003, 2004).[5] Consequently, the university is an institution that not only creates, conserves and transmits knowledge

[5] Historically, the first academic revolution included an integration of teaching and research initiated by Wilhelm von Humboldt in the late 19th and early 20th century.

but also commercializes knowledge (Etzkowitz, 2003, 2004). Thus, universities must increasingly cope with patenting, licensing, collaborations with industry, science parks, and university spin-offs (Mowery et al., 2004; van Looy et al., 2011). The changing role for universities is best summarized by the phrase *entrepreneurial university* coined by Henry Etzkowitz (Bercovitz & Feldman, 2006).

Knowledge and technology can be transferred through various means from universities to the private sector (e.g., Lockett et al., 2005; Phan & Siegel, 2006; Siegel et al., 2007). For example, Bongers et al. (2003) identified more than 1,400 transfer channels; such channels range from informal (e.g., conferences and networks) to formal (e.g., patenting and licensing) (e.g., Cohen et al., 2002; Bongers et al., 2003). This thesis focuses on formal channels, particularly for patent-related transfer activities.

1.3 Policy initiatives that foster university-to-industry technology transfer

As discussed above, there are several reasons why universities are currently more active in technology transfer to industry. One such reason is the change in legal parameters for academic research ownership in many countries. In the following, background information on important legal reforms in the United States and Europe are outlined.

1.3.1 The Bayh-Dole Act as a trailblazer

The Patent and Trademark Law Amendments Act (Bayh-Dole Act) from 1980 comprised the most prominent change in the United States' technology transfer policy. In this act, universities were permitted to file patents for inventions that originated from research financed by federal agencies. Because federal agencies dominate U.S. research funding, universities own the IP for inventions that emerged from the larger share of U.S. university research (Mowery & Sampat, 2005). Before the Bayh-Dole Act, several federal agencies transferred patent rights to universities under institutional patent agreements or individual universities and agencies negotiated bilateral agreements that regulated transfer activities (e.g., Mowery et al., 2001; Mowery & Sampat, 2001a, 2005; Geuna & Rossi, 2011). Consequently, the Bayh-Dole Act primarily simplified the legal conditions for academic patent ownership, and the IP shifted toward the university (Mowery & Sampat, 2001a).

A sharp increase in university patenting was observed shortly after introducing the legislative reforms (e.g., Henderson et al., 1998).[6] Scholars and policy-makers (e.g., OECD, 2003) attributed the significant growth in U.S. university patenting and licensing to the Bayh-Dole Act (Mowery & Sampat, 2005). However, the increase must be interpreted in light of historical development for U.S. academic patenting, particularly for comparing European and U.S. university patenting activities.

First, the link between universities and industry has a long history in the United States. Rosenberg & Nelson's (1994) research showed that close collaborations between universities and industry continued through the 20th century. "This research collaboration frequently included industrial funding of academic research, patenting and licensing of the results of such research to industrial entities and was rooted in the unusual environment of institutional variety, autonomy and competition that distinguishes the US university system from those of most other industrial economies" (Mowery & Sampat, 2001a, p. 351).

Second, U.S. universities, particularly public universities, were actively patenting research in the early 20th century. Patenting activities increased during the 1970s and are now primarily driven by private university activities. Such an expansion in academic patenting led to the development of patent policies in U.S. universities (Mowery & Sampat, 2001b, a, 2005).

Third, institutions responsible for university IP management have a long tradition in the Unites States. The Research Corporation,[7] which is responsible, inter alia, for managing IP in educational or research institutions, was founded in 1912 by Frederick Gardner Cottrell (Mowery & Sampat, 2001a).[8] In 1925, the University of Wisconsin created the Wisconsin Alumni Research Foundation as a separate legal entity affiliated with the university and responsible for patent and licensing management of faculty inventions.[9] Several universities have followed the example set by the University of

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6 "In 1965 just 96 U.S. patents were granted to 28 U.S. universities or related institutions. In 1992 almost 1500 patents were granted to over 150 U.S. universities or related institutions. This 15-fold increase in university patenting occurred over an interval in which total U.S. patenting increased less than 50%, and patents granted to U.S. inventors remained roughly constant" (Henderson et al., 1998, p. 119).

7 For a more detailed discussion on history for the Research Corporation, see Mowery & Sampat (2001a).

8 Frederick Daniel Cottrell was chemist at the University of California-Berkeley and invented the electrostatic precipitator. The invention was patented in 1907 for licensing and royalties to finance further scientific research. To facilitate such steps, he required an organization to manage the licenses, and consequently, the Research Corporation was founded (Mowery & Sampat, 2001a).

9 Similar to historical development of the Research Corporation, Harry Steenbock invented a method for increasing vitamin D levels in food and drugs and initiated the creation of the Wisconsin Alumni Research Foundation (Mowery & Sampat, 2001b).

Wisconsin; other universities, such as the Massachusetts Institute of Technology (MIT), signed a contract with the Research Corporation. Based on the agreement with MIT, the Research Corporation developed into a national licensing intermediary for universities (Mowery & Sampat, 2001b). In the late 1960s, well before the Bayh-Dole Act, universities began to manage their patent portfolios internally and developed technology transfer capabilities (Mowery & Sampat, 2001a, 2005). Coupé (2003) empirically estimated the effect of the Bayh-Dole Act on U.S. university patenting activities. He did not observe a direct effect of the Act; however, the establishment of TTOs (most likely in reaction to the Bayh-Dole Act) is associated with an increase in academic patenting.

To conclude, U.S. universities have a long tradition and much experience in university-to-industry technology transfer. The Bayh-Dole Act accelerated development of universities' direct involvement in technology transfer, but this trend began before the Bayh-Dole Act and was further augmented by the rise of biomedical research [10] (Mowery et al., 2001; Mowery et al., 2004; Mowery & Sampat, 2005).

1.3.2 European legislative reforms

Although evidence for the effects of the Bayh-Dole Act in the Unites States is limited, it was a model for IP regulatory changes (beginning in the late 1990s) to foster technology-to-industry transfer in many European countries (Mowery & Sampat, 2005; Geuna & Rossi, 2011). Such reforms were primarily driven by the conjecture (the "European Paradox") that European universities produce excellent research but lack the capacity to transfer such research to industry, particularly compared with U.S. counterparts (OECD, 2003; Mowery & Sampat, 2005; Dosi et al., 2006).

Europe has two ownership systems in academic IP, institutional ownership and inventor ownership (professors' privilege). In the former, the university owns inventions that originate with their faculty; in the latter, faculty members retain the IP for their inventions. Geuna & Rossi (2011) developed a typology to group countries with similar IP regulatory developments. The first group includes the early adopters (UK, Spain and Switzerland) of the institutional ownership system. The second group comprises countries (France and Greece) with institutional ownership model in practice before 2000. However, compared with the first group, universities in such countries weakly enforced their ownership rights. Northern European countries (Germany, Denmark,

[10] „Non-biomedical university patents increased by 90% from the 1968–1970 period to the 1978–1980 period, but biomedical university patents increased by 295%" (Mowery & Sampat, 2005, p. 121).

Finland, Norway and Austria) traditionally practiced an inventor ownership model (professors' privilege) and changed the IP regulations to an institutional ownership model after 2000. By abolishing the professors' privilege, IP moved away from the inventor toward the university. Italy is in the fourth group and, in contrast to the general trend, changed from an institutional to an inventor ownership model. In the fifth group, Sweden maintained the inventor ownership model.

The typology indicates a general trend towards institutional ownership[11]; however, the systems differ among countries, and individual university bylaws further complicate such comparisons (Geuna & Rossi, 2011). Table 1 provides an overview of the alternative principles for the institutional ownership system. The first column shows countries that support a "pre-emption rights" principle. Under this principle, the first invention owner is the researcher; however, the university can claim the invention within a certain period. The "automatic ownership" principle states that the university is the invention owner, and typically, the right cannot revert back to the inventor. Other countries (e.g., Germany) enforce a "hybrid system"; under such a system, the ownership principle depends on the type of invention. In Germany, the law differentiates between "service inventions" (inventions during the term of employment) and "free inventions" (inventions outside work for the university). The first invention falls under the automatic ownership principle and the latter under the pre-emption right principle (Geuna & Rossi, 2011).

Table 1: Principles underlying institutional ownership systems

Pre-emption rights principle	**Automatic ownership principle**	**Hybrid system**
Austria	France	Finland
Belgium	The Netherlands	Germany
Czech Republic	Poland	Greece
Denmark	Portugal	Hungary
Norway	Slovak Republic	
	Slovenia	
	Spain	
	UK	

Source: Own research (Geuna & Rossi, 2011)

With the legislative changes, initiatives emerged at the national and university level to foster university-to-industry technology transfer. The Lisbon Strategy published in 2000 was a major action by the European Commission. In Germany, abolishment of

11 For a critical discussion of the institutional ownership model see for example Kenney & Patton (2009, 2011).

the professors' privilege was part of the *Verwertungsoffensive* ("exploitation offensive"), which was initiated by the federal government. Another part of this initiative was support for establishing *Patentverwertungsagenturen* ("patent exploitation agencies") to increase technology transfer by German universities (BMBF, 2001).

Policy initiatives and the rising interest in university-to-industry technology transfer led to establishment of TTOs in almost all major universities in the United States and Europe (Rogers et al., 2000; Siegel et al., 2007; Grimaldi et al., 2011). A large body of scholarly literature emerged that analyzed TTO productivity and the factors that influence success in technology transfer activities. Moreover, academic patenting in Europe and the United States before and after such legal reforms attracted the attention of many researchers. In the following, a comprehensive overview of the relevant literature is provided and research gaps are discussed.

1.4 Technology transfer offices

1.4.1 Technology transfer offices as intermediaries

Hoppe & Ozdenoren (2005) generally analyze the rationale for innovation intermediaries (such as TTOs or venture capitalists). They argue that the basis for intermediation is investment failure induced by innovation uncertainty. By acquiring the expertise to separate profitable from unprofitable inventions and match inventions with suitable investors, the expected payments exceed the initial investment by the intermediary. By acquiring expertise, the asymmetric information between the intermediary and the potential investors increases; however, a sufficiently large invention pool and success-based compensation scheme facilitates viable intermediation. Similarly, Macho-Stadler et al. (2007) theoretically demonstrated that TTOs can reduce asymmetric information by building and maintaining reputation, provided that the invention pool is sufficiently large.

Jensen et al. (2003) modeled the transfer process as a game with the TTO as a transfer agent for both the faculty and university administration. The administration was modeled as agent for the faculty. They summarized that "[t]hese offices are responsible for facilitating faculty disclosure of inventions, evaluating those inventions disclosed, as well as finding licensees and executing contracts on behalf of the central administration for the university (which owns the inventions)" (Jensen et al., 2003, p. 1291).

Siegel et al. (2003) supports this view and described the stylized technology transfer process in four stages. In the first stage, a scientific invention must be disclosed to the TTO. In the second stage, the TTO evaluates the invention (particularly the commercial potential) and determines whether it is suitable for patenting. In the third step, the TTO markets the invention and attempts to find an industry partner or individual entrepreneurs for licensing. In the final stage, the licensing agreement must be negotiated. Accordingly, the key function of a TTO is to act as an intermediary between university researchers and industry (firms, entrepreneurs and venture capitalists) (Siegel et al., 2007).

In sum, TTOs are primary agents (in additional to faculty, university administration, and industry) in the university-to-industry technology transfer process and are perceived as an important influential factor on technology transfer performance.

1.4.2 Technology transfer offices performance

Empirical studies on technology transfer office effectiveness identified TTO productivity determinants (measured by the number of patents, the number of licenses, licensing revenues, the number of spin-outs, or the number of and income from R&D research contracts) in the following categories: (1) regional demand for technology, (2) quality and type of technology produced by the academic institution, (3) university institutional variables, and (4) TTO characteristics. In the following, the primary findings in the respective categories demonstrated through selected studies are discussed (cf. A-2 in the Appendix). Studies that have exclusively analyzed academic institutions' spin-out activities are not considered in the scope of this thesis. The sample, statistical approach and performance measure (dependent variable(s)) used in each study are summarized in A-1 in the Appendix.

(1) Regional demand for technology. Friedman & Silberman (2003) analyzed U.S. research university technology transfer performance, which was measured by the number of licenses, number of licenses with income and total licensing income from 1997-1999. They confirmed the hypotheses that more licenses and licensing income are generated when the university is located in an area with a relatively high technological concentration (e.g., a high concentration of technology firms and an entrepreneurial climate). Foltz et al. (2000), Link & Siegel (2005), Lach & Schankerman (2004, 2008), and Belenzon & Schankerman (2009) confirmed this finding. However, Siegel et al. (2003) and Chapple et al. (2005) only confirmed a significant relationship for the number of licenses but did not find a significant association with licensing revenue. In contrast, van Looy et al. (2011) analyzed 105 universities in Europe and estimated the positive effects from local R&D intensity on universities' spin-off activity and did not

observe a significant effect on the number of patents and levels of contract research. However, the authors find positive effects on spin-off activities. Contrary to expectations, Hülsbeck et al. (2013) measured a negative coefficient for industry concentration on the number of invention disclosures in Germany. One explanation for this result is "(…) that industrial complementarity (Jacobian-spillover effects) dominates Marshallian-spillover effects by economies of scale (…)" (Hülsbeck et al., 2013, p. 211)[12].

(2) Quality and type of technology produced by the academic institution. The university's faculty quality, research orientation (e.g., the disciplines represented at the university) and academic rank were considered important determinants of technology transfer effectiveness in previous studies. The vast majority of studies showed a positive effect from university/faculty quality (e.g., Foltz et al., 2000; Powers, 2003; van Looy et al., 2011; Hülsbeck et al., 2013). Lach & Schankerman (2004, 2008) found no significant effect from academic quality on licensing income. Moreover, Caldera & Debande (2010) estimated that university quality (measured by the number of publications in top scientific journals) has a negative effect on the number of licenses but a positive effect on the number of R&D contracts and R&D contract income. This result may indicate that basic research is less likely to be licensed to firms but more likely transferred via research collaborations. Thursby & Kemp (2002) followed this argument and found a negative relationship between university research quality and commercialization efficiency. Moreover, their results indicate differences in the importance of discipline for licensing activity. Biological science and engineering (compared with physical science) are more important in this context. Belenzon & Schankerman (2009) controlled for faculty shares in six technology areas (biomedical, other biological, chemistry, computer science, engineering, and physical sciences) in their regression analysis and found significant differences in three out of four output variables (number of licenses, licensing income, and total number of spin-offs). In contrast, Lach & Schankerman (2004, 2008) did not find heterogeneity in technology transfer performance between technology fields.

(3) University institutional variables. University institutional variables such as university size, presence of a medical school, universities' private vs. public status, and universities' financing structure are considered as important determinants for

12 Marshallian-spillovers emerge among firms in the same industry. Jacobian-spillovers arise among firms using similar technologies but not competing on the same market (Hülsbeck & Lehmann, 2010).

technology transfer performance.

Research on the effects from the presence of a medical school produced mixed evidence. Hülsbeck et al. (2013) and Siegel et al. (2008) found a positive association for German and U.S. universities, respectively. Friedman & Silberman (2003), Powers (2003), Siegel et al. (2003), Sine et al. (2003) and Link & Siegel (2005) found no evidence that the presence of medical school enhanced performance. Thursby et al. (2001) documented significant positive results for the number of licenses but no significant results for royalty income. Similarly, Caldera & Debande (2010) found that only the number of R&D contracts was positively associated with the presence of a medical school in Spanish universities. No association was detected for R&D contract income, number of licenses, royalties and number of spin-offs. Belenzon & Schankerman (2009) reported significant positive results for licensing income and negative effects for the number of licenses. Conversely, Thursby & Kemp (2002) and Anderson et al. (2007), for example, found negative effects from this variable on the efficiency of technology transfer.

Another important variable, at least for U.S. universities, is the public status of the university. The underlying assumption is that private universities are more efficient at technology transfer compared with public universities because they have fewer service and teaching commitments (Thursby & Kemp, 2002) and more intensive contacts to private firms (Caldera & Debande, 2010). Lach & Schankerman (2008) suggested that faculty at private firms are more responsive to royalty incentives. This assumption is supported by Thursby & Kemp (2002) and Lach & Schankerman (2004). Powers (2003), Siegel et al. (2003) and Anderson (2007) did not find statistically significant effects from university status. In a study by Belenzon & Schankerman (2009), a significant positive effect from private status diminishes with a control for providing incentive schemes to TTO personnel. The researchers found a negative effect on the number of spin-offs, which was also confirmed by Caldera & Debande (2010).

For the variables university size, presence of an engineering school, polytechnics and land-grant universities, amount of federal and industrial funding, incubators, as well as research expenditures, studies have consistently observed a significant positive or insignificant relationship with technology transfer effectiveness (e.g., Foltz et al., 2000; Rogers et al., 2000; Friedman & Silberman, 2003; Powers, 2003; Lach & Schankerman, 2004, 2008; Caldera & Debande, 2010; Hülsbeck et al., 2013).

(4) Characteristics of the TTO. TTO size (most commonly measured by the

number of full-time employees at a transfer organization) and experience (measured by the transfer organization age) are positively correlated with the performance for the majority of studies (e.g., Rogers et al., 2000; Thursby et al., 2001; Thursby & Kemp, 2002; Powers, 2003; Chapple et al., 2005; Siegel et al., 2008). In additional studies, TTO size is positively associated with the number of licenses, but it has no significant effect on licensing income (Siegel et al., 2003; Link & Siegel 2005; Caldera & Debande, 2010). Chapple et al. (2005) and Siegel et al. (2008) found decreasing returns of scale, and they also found that older TTOs are less efficient. The latter indicates that experience yields no effect.

The royalty share provided to the inventor and number of invention disclosures are associated with performance enhancement without exception (Siegel et al., 2003; Sine et al., 2003; Lach & Schankerman, 2004; Chapple et al., 2005; Link & Siegel, 2005; Lach & Schankerman, 2008; Caldera & Debande, 2010).

In sum, scholars have discussed several determinants of technology transfer performance. They have provided empirical evidence suggesting that regional factors as well as technology, university and TTO characteristics are important determinants of technology transfer performance. However, organizational variables, such as the governance structure of TTOs, have largely been neglected.

1.4.3 Organizational structure of technology transfer offices

Recently, scholars began to consider TTO organizational factors (e.g., Bercovitz et al., 2001; Link & Siegel, 2005; Sellenthin, 2009; Conti & Gaulé, 2011; Hülsbeck et al., 2013). To the best of my knowledge, Bercovitz et al. (2001) is the first study that considers TTO organizational form as a determinant for academic patenting and licensing behavior. They analyzed four different TTO organizational forms: the functional, multidivisional, holding, and matrix forms. The functional form is a "(…) centralized, functionally departmentalized structure in which decision-making and coordination responsibilities lie with a small team of top executives (…)" (Bercovitz et al., 2001, p. 6). The multidivisional form is composed of semi-autonomous divisions with a strong central office. The holding form is similar to the multidivisional form, but the central office has a smaller role in coordinating actions across divisions and, therefore, is described as weak. Finally, the matrix form has both a functional and divisional structure. Information processing capacity, coordination capability, and incentive alignment are specific for each organizational form and determine technology transfer efficiency.

Siegel et al. (2003) showed that variations in TTO performance cannot be fully explained by environmental (state-level economic growth as well as local firm R&D activity) and institutional factors (public status, presence of a medical school, and TTO age). They argued that organizational practices should be considered an important determinant of TTO performance. Based on this finding, Link & Siegel (2005) include a variable that describes organizational structure in the production framework. However, they only distinguish between centralized and decentralized structures and found no significant influence on relative TTO efficiency. Conti and Gaulé (2011) investigated differences in technology transfer performance for the United States and Europe. They found that the licensing revenue, but not the number of licenses, differ for European and U.S. TTOs. The authors argue that the difference is related to TTO organizational practices and staffing. Markman et al. (2005) analyzed the correlation between TTO organizational structure and licensing strategies as well as new venture formation in the U.S.

Despite the growing interest in and research on university-to-industry technology transfer, little is known on how technology transfer activities are organized in European universities (Clarysse et al., 2005). To the best of my knowledge, only a few studies have dealt with TTO organizational structure in Europe (Debackere & Veugelers, 2005; European Commission, 2007; Meyer & Tang, 2007; Mathieu et al., 2008; Muscio, 2010; Hülsbeck et al., 2013).[13] As discussed in Section 1.3, Europe practices differ from the United States. Not only does university culture differ between the two continents but corporate culture also differs with respect to university-to-industry technology transfer. As an intermediary between industry and universities, the TTO must adapt to such environmental factors. Consequently, transferring research from U.S. to European TTOs is not straightforward. Furthermore, the national and cultural variation in Europe is far greater than the United States, which provides an opportunity for studying contingencies in much more detail.

The contributions reviewed in this section provide many insights; however, they typically focus on selected aspects of the TTO governance structure and are only partially based on theoretical foundations. The paper "Governance typology of universities' technology transfer processes" (Study 1, cf. Chapter 2) addresses this gap by theoretically deriving a typology for university TTOs and comparing it with case studies on sixteen European universities.

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13 The primary results from such studies are discussed in Study 1 (cf. Chapter 2).

1.5 Academic patenting

1.5.1 University-owned and university-invented (but not -owned) patents

The discussion on technology transfer performance showed that many studies have used the number of patent applications by a university (so called university-owned patents) as an indicator of output. However, such studies ignored university-invented (but not -owned) patents. These patents originated in the university (at least one faculty or staff member is listed as an inventor) but are owned by a separate institution (primarily firms or public research organizations). The term academic patents (the term university patents is used synonymously in what follows) comprises both categories.

Prior findings indicate that the number of university-owned patents dramatically underestimates academic patents for general patent statistics. Saragossi and van Pottelsberghe de la Potterie (2003) analyzed the Université Libre de Bruxelles (ULB; in Belgium) patent portfolio and concluded that 68% to 78% of university patents were not owned by the university. Based on the PatVal survey, Crespi et al. (2006) found that for Germany, Italy, France, UK, Spain, and the Netherlands the majority of university patents included in the survey were university-invented (but not -owned). Lissoni et al. (2008) used name-matching based on university staff lists for France, Italy and Sweden. They found that approximately 60% to 80% of all university patents in these countries were owned by firms and the share of university patents was comparable to the United States. Lissoni et al. (2009) reproduced the same results for Denmark, and Della Malva et al. (2013) provided such for France. Prior studies also identified high levels of university-invented (but not -owned) patents in Germany (e.g., Schmoch, 2007; von Proff et al., 2012). For the U.S., levels of university-invented (but not -owned) patents were much lower, but considerable. Jensen et al. (2007) and Thursby et al. (2009) reported that 26% to 28% of U.S. academic patents were not owned by universities (but primarily by firms). The UK was intermediate with 40% of academic patents owned by universities (Sterzi, 2013). Table 2 summarizes the available evidence for European countries and the United States.

Table 2 Share of university-owned patents identified in prior studies

Author	Country	Database	% University-owned patents	Time period
Crespi et al. (2006)	Germany	PatVal Survey	4%	1993-1997
	Italy		4%	
	France		12%	
	UK		32%	
	Spain		53%	
	Netherlands		20%	
Della Malva et al. (2013)	France	KEINS	10%	1994-2002
Jensen et al. (2007)	US	USTPO	65%	1993-2004
Lissoni et al. (2008)	France	KEINS	8%	1994-2001
	Italy		8%	
	Sweden		4%	
Lissoni et al. (2009)	Denmark	KEINS	11%	1994-2003
Sargossi & van Pottelsberghe de la Potterie (2003)	Belgium-ULB	EPO	22%	1985-1988
			32%	1989-1993
			28%	1994-1998
Schmoch (2007)	Germany	GPTO	27%	2004
Sterzi (2013)	UK	KEINS	40%	1990-2001
Thursby et al. (2009)	US	USTPO	62%	1990-2004
von Proff et al. (2012)	Germany	GPTO	30%	1991-2006

Source: Own research

Notes: “EPO” stands for European Patent Office, “GPTO” for the German Patent and Trademark Office, “USPTO” for the United States Patent and Trademark Office; “KEINS” for Knowledge-Based Entrepreneurship: Innovation, Networks and Systems.

1.5.2 University ownership determinants

Prior research that considered ownership patterns for academic patents focused on (1) comparing university-owned and university-invented (but not -owned) patent characteristics (e.g., Thursby et al., 2009; Czarnitzki et al., 2012; Lissoni et al., 2012), (2) comparing academic and firm-owned patent characteristics (e.g., Czarnitzki et al., 2011), and (3) analyzing the effect from legislative changes (e.g., Frietsch et al., 2011; Lissoni et al., 2012; von Proff et al., 2012; Della Malva et al., 2013). Most studies were conducted at the country-level.

Jensen et al. (2007) and Thursby et al. (2009) began studies on academic patents in the U.S. Jensen et al. (2007) presented a theoretical model and empirical analysis that explained ownership patterns for academic patents. Based on the assumption that university-invented (but not -owned) patents primarily result from faculty consulting, they hypothesized that ownership is not only influenced by faculty decisions but also by funding agencies decisions (government and industrial). In their two-stage model, the funding agency and firm simultaneously choose funding levels for the project. The firm then chooses a unit consulting fee, and the researcher chooses her consulting time. The model predicts that higher-quality faculty yield a higher probability that patents are owned by the university. This was supported by their empirical analysis.

Thursby et al. (2009) explored how patent ownership relates to patent characteristics, inventor field, and university characteristics. Based on 5,818 unique patents from 2,900 different inventors, the authors found that university-owned patents are more basic (less incremental). The hypothesis that university-owned patents are less important (measured by the number of forward citations) can only be confirmed in models without technology fixed effects. Moreover, the empirical results showed that university ownership is more likely for public universities and universities that offer a higher royalty share.

In Europe, Lissoni et al. (2012) and Della Malva et al. (2013) began to analyze the relationship between university characteristics (e.g., university size and presence of a TTO) and academic patent ownership patterns. However, empirical knowledge on determinants for academic patent ownership patterns is not fully consistent with the strong interest in this subject. In particular, determinants, such as university performance in additional areas and organizational identity, have largely been neglected. Study 3 (cf. Chapter 4) aims at filling this research gap. An enhanced understanding of such factors will aid in assessing legal reforms and evaluating differences between universities.

1.5.3 Methodological issues

To analyze academic patent ownership patterns, a patent dataset at the university level is required, which implies that a method for identifying faculty members with patent applications is necessary. Finding scientist names in patent databases was termed the “name game” by Manuel Trajtenberg (2006) and is accompanied by the “who is who” problem at the individual inventor level.

The leading studies on European countries (notably, Lissoni et al., 2008; Lissoni et al., 2009) played the “name game” by systematically matching professor and inventor names. Patent applications at the EPO were used as the dataset. However, using only patent applications at a single office has severe limitations: approximately 85% of applications in German university patent portfolios are filed at the German Patent and Trademark Office (GPTO); thus, reliance on the national office is strong. Consequently, considering only inventors on EPO patent applications underestimates inventive activity and increases the risk of selection bias (Study 3, cf. Chapter 4).

Scholars in Germany circumvented the problem by searching for the title of professor in patent databases. However, this approach has substantial drawbacks. On the one hand, it is unclear how many academic inventors are missed or are erroneously entered in the sample using this method (e.g., honorary professors unaffiliated with the university might use their title in the patent application). On the other hand, allocating the patents identified with the affiliated university (where the invention originated) would be costly and time-consuming. Consequently, to identify academic patents in Germany, the matching technique was adjusted and examined. The approach used is presented and discussed in Study 2 (cf. Chapter 3).

1.6 Summary

University tasks have changed in the last few decades to include the “third mission” in addition to research and teaching. Three interrelated driving factors were identified: (1) rise of a knowledge-based economy; (2) tighter budget constraints for universities; (3) government policies and university initiatives to foster university-to-industry technology transfer. This development challenges universities with respect to IP management and professional technology transfer activities. In response, the TTO has emerged as intermediary in the transfer process from university to industry and as such plays an important role in the process’ effectiveness. Several studies provide empirical evidence to support this perspective. The TTO governance structure, particularly in Europe, has been widely ignored in this discussion. However, neglecting the governance structure risks a biased perception of the relative technology transfer performances of TTOs. In turn, to incorporate the governance structure in empirical studies, a systematic analysis is required. The paper “Governance typology of universities’ technology transfer process” (Study 1, cf. Chapter 2) addresses this research gap.

In many studies on technology transfer performance, university-owned patents are an indicator of output. However, many inventions that originated with the faculty are owned by firms, individuals, or public research organizations in Europe. Neglecting such (university-invented but not -owned) patents generates a biased assessment of university innovative performance. However, identifying university-invented (but not –owned) patents is associated with many obstacles. The paper "Playing the 'Name Game' to identify university patents in Germany" (Study 2, cf. Chapter 3) presents and assesses a new approach to solve such problems.

Generally, determining the number of patents for innovation studies is not straightforward. Using the number of applications at a single office (e.g., only patent applications at the EPO) may generate bias. The issue is discussed and a simple test for detecting bias is proposed in the paper "Selection bias in innovation studies: A simple test" (Study 3, cf. Chapter 4).

Finally, the importance of university-invented (but not -owned) patents in European universities raises the question what factors influence the type of ownership for academic patents. In particular, previous studies have analyzed university-owned and university-invented (but not -owned) patent characteristics at the national level. Studies at the university level have not investigated the relationship between university characteristics and ownership patterns. The paper "When do universities own their patents? An explorative study of patent characteristics and organizational determinants in Germany" fills this gap (Study 4, cf. Chapter 5).

2 Governance typology of universities' technology transfer processes (Journal of Technology Transfer)

2.1 Summary

The paper "Governance typology of universities' technology transfer processes" was authored by Anja Schoen, Bruno van Pottelsberghe de la Potterie and Joachim Henkel. The version herein is published in the Journal of Technology Transfer.

Only a few studies have explicitly considered the TTO organizational structure as a determinant for university technology transfer effectiveness (cf. Section 1.4). The few existing studies primarily concentrated on the U.S. and considered only one dimension of governance. However, TTO governance must be better understood for a more suitable comparison of technology performance between universities and to facilitate analytical support for university management. The aim for this article was to systematically analyze governance structure of TTOs in Europe. Thus, the article first presents a theoretical discussion of feasible configurations of TTOs' governance structures. The second section compares 16 European case studies with the new typology and discusses the advantages as well as disadvantages of the governance structures.

Four independent dimensions are identified in the first section of the theoretically discussion: (a) degree of discipline specialization, (b) degree of task specialization, (c) level of autonomy, and (d) degree of exclusivity. Each dimension can include several values, and the advantages and disadvantages of these values were discussed. In the second portion, infeasible value combinations were excluded, which produced feasible configurations (potential structure to govern TTOs). Four general types of TTOs were discerned: (1) classical TTO, (2) autonomous TTO, (3) discipline-integrated technology transfer alliance (TTA), and (4) discipline-specialized TTA.

The second portion classified case studies from six different European countries, Belgium, France, Germany, Switzerland, the Netherlands and the United Kingdom in accordance with the new typology and discussed implications for the technology transfer process with a focus on IP-related technology transfer activities.

This article contributes to the existing literature in two ways. First, it theoretically analyzed the prevailing diversity in organizational models and provides a conceptual understanding on how universities organize technology transfer activities. Second, this article presents an empirical overview on how the governance structure affects the technology transfer process, particularly IP management.

I drafted this article, which was continuously advanced through discussions with the co-authors. Florence Honoré (under supervision of Bruno van Pottelsberghe de la Potterie), and I conducted the interviews. I interviewed six TTO managers and interpreted the complete interview set as well as secondary material.

2.2 Publication

Schoen, A., van Pottelsberghe de la Potterie, B., Henkel, J. (in press): Governance typology of universities' technology transfer processes. *The Journal of Technology Transfer.* doi: http://dx.doi.org/10.1007/s10961-012-9289-0.

3 Playing the ‘Name Game’ to identify university patents in Germany

3.1 Summary

Anja Schoen, Dominik Heinisch and Guido Buenstorf authored the study “Playing the ‘Name Game’ to identify university patents in Germany”, which is submitted to Scientometrics and published as working paper.

One of the major challenges for research on academic patenting is collecting relevant patent data. Two main sources for this problem have been identified. First, a complete faculty name list is necessary to find faculty members on patent applications. Second, matching and filtering algorithms must be developed and examined. The latter step is a very complex task, particularly for large countries, and how well the algorithms perform depends on the criteria selected and how the similarity score is determined.

The first problem was solved by Guido Buenstorf and Dominik Heinisch by providing a complete list of professors’ names based on Kürschners Gelehrtenkalender. The second problem was solved in previous studies for a number of European countries (e.g., France). However, the approach used cannot be transferred to Germany without severe limitations. Thus, in collaboration with the co-authors, I developed a method to solve the “who is who” problem for German academic inventors.

The proposed methodology comprises five steps. In the first step, the lists of professors’ and inventors’ names are cleaned. In the second step, professors’ names are compared to inventors’ names (professor-inventor name comparison). Three different algorithms are used in this step (a 2-gram algorithm, Jaccard similarity coefficient and simple-string matching algorithm). In the third step, identical inventors are identified (inventor-inventor filtering). In the fourth step, professors are as accurate as possible allocated as inventor(s) (professor-inventor filtering). In the last step, the dataset is manually examined.

The algorithms presented differ from previous research on three main points. First, scholars considered only inventors on patent applications filed at the EPO. Because a single-office application count would dramatically underestimate the inventive activity of German academics and introduce selection bias (Study 3, cf. Chapter 4), we considered patents applications worldwide. Second, we applied an additional step (professor-inventor name comparison) to our methodology in contrast to previous research. This step is advantageous because we can still manage the large

dataset from a worldwide patent application count and the size of the country. Third, to decide whether inventor-inventor pairs or inventor-professor pairs are the same person we did not use cumulative similarity scores, which has previously been used, and we applied data mining techniques.

The results from inventor-inventor filtering were compared to results from the matching approach conducted by the ESF-APE-INV project. Furthermore, the final dataset was compared to results from a simple search for the professor title in the patent database, which is a commonly used approach in Germany. Guido Buenstorf provided the data for the latter step.

This article provides several lessons for future studies that use patent data at the inventor level. Moreover, the results show that assessing academic technology transfer based on seemingly straightforward indicators, such as university-owned patents, might produce incorrect results.

This article began through a close collaboration with Guido Buenstorf and Dominik Heinisch. I developed and cleaned the dataset as well as the professor-inventor name comparison (using the 2-gram algorithm and Jaccard similarity coefficient). Dominik Heinisch provided results from a professor-inventor name comparison using the simple-string matching algorithm. Moreover, I integrated the additional matching step. Dominik Heinisch and I adapted the data-mining techniques to the filtering steps. Finally, I compared the final dataset with alternative approaches and drafted the paper. Guido Buenstorf and Dominik Heinisch provided feedback on each step and actively revised this article.

3.2 Publication

Schoen, A., Heinisch, D., Buenstorf, G. (2013): *Playing the 'Name Game' to identify university patents in Germany*. Working Paper. Available at SSRN: http://ssrn.com/abstract=2289218.

4 Selection bias in innovation studies: A simple test (Technological Forecasting and Social Change)

4.1 Summary

The study “Selection bias in innovation studies: A simple test” is authored by Gaétan de Rassenfosse, Anja Schoen and Annelies Wastyn and published in Technological Forecasting and Social Change.

To assess the inventive output of an organization, the number of patent application is often used. The majority of studies count only patent applications at a single patent office (“single-office count”), which introduces selection bias. The single-office count generates selection bias because the filing route is not random and systematic factors affect the decision. Gaétan de Rassenfosse developed a way to test for such selection bias in innovation studies.

The new methodology was applied to two novel datasets, which included data from Belgian firms and German universities. The Belgian data were provided by Gaétan de Rassenfosse and Annelies Wastyn, the German data were provided by me. For this study, only patent applications by the university were used. These datasets are particular useful for illustrating selection bias and validating the proposed investigation because they provide two opposing institutional contexts: Belgian firms file approximately 85% of patents at the EPO and German universities first file 85% of priority applications at the GPTO.

In both datasets, we found selection bias induced by a single-office count. Interestingly, for the German university-owned patents, significant biases were also detected by using patent applications filed at the GPTO.

In conclusion, this article provides a simple method to test for selection bias in innovation studies, which also applies to other empirical settings as invention production functions. The empirical results demonstrate that the filing route is not random, and consequently, estimates based on the number of patent applications at a single office should be treated with caution.

I contributed to this paper by providing the German university-owned patent dataset and analyzing it in close collaboration with Gaétan de Rassenfosse. Moreover, I took an active role in commenting on and improving the flow of this article.

4.2 Publication

de Rassenfosse, G., Schoen, A., Wastyn, A. (in press): Selection bias in innovation studies: A simple test. *Technological Forecasting and Social Change*. doi: http://dx.doi.org/10.1016/j.techfore.2013.02.012.

5 When do universities own their patents? (Industry and Innovation)

5.1 Summary

The study “When do universities own their patents? An explorative study of patent characteristics and organizational determinants in Germany” is authored by Anja Schoen and Guido Buenstorf and is accepted for publication in Industry and Innovation.

The goal of this article was to provide detailed evidence on how patent characteristics and organizational determinants affect ownership of German academic patents. Prior research has demonstrated that inventions originating in European universities are often not owned by the universities, but by other institutions (e.g., public research organization or firms). Limited evidence suggests that patent characteristics are associated with ownership patterns. However, university-level determinants, particularly performance in other areas and university organizational identity (technical universities vs. general research universities), are largely neglected in such discussions. However, understanding such relationships is important for better understanding effects from legislative reforms and the differences between academic institutions in university-to-industry technology transfer. The paper was aimed at filling this research gap by analyzing ownership patterns for German universities.

Thus, a new dataset on German academic patents was used and additional information on universities was collected from different sources (e.g., from the German Federal Statistical Office (*Statistisches Bundesamt*) and the German Research Foundation (*Deutsche Forschungsgemeinschaft*)). Probit models were used for the empirical analysis. To analyze differences in the effects from independent variables on technical universities and general research universities, a split sample approach was used and the differences were investigated through predicted probabilities. My primary contribution was providing relevant data, constructing the research design and econometric analysis. The approach and results were discussed with Guido Buenstorf and further developed.

The results are the first evidence that universities in Germany quickly adapted to the new legal framework. We did not find a significant difference in the share of university-owned patents between technical and general research universities. However, empirical results suggest that patent characteristics and university performance indicators relate differently to the likelihood of university ownership for the two university types. Patents owned by general research universities seem to be more basic and less important than university-invented (but not -owned) patents. In contrast, university-invented (but not -owned) and university-owned patents by technical universities have very similar characteristics. Moreover, performance in other realms relates differently to the ownership patterns for the two university types. The findings imply that different perspectives are valid on how invention ownership by universities from the faculty relates to technology transfer performance. Based on the empirical findings, the conclusions and implications were discussed between the authors. The paper was drafted by me. Guido Buenstorf took an active role in revising as well as commenting on this article, which generated substantial improvements.

5.2 Publication

Schoen, A., Buenstorf, G. (forthcoming): When do universities own their patents? An explorative study of patent characteristics and organizational determinants in Germany. Accepted for publication in *Industry and Innovation*.

Appendix

A-1: Overview of selected papers analyzing technology transfer performance

Authors	Country	Period	Sample size	Main Data Source	Statistical technique	Performance measurement (dependent variable(s))
Anderson et al. (2007)	US	2001-2004	54 universities	The Chronicle of Higher Education	DEA, linear regression	licensing income ($M) number licenses and options executed number spin-offs number US patents filed/issued
Belenzon & Schanker-man (2009)	US	1995-1999	86 universities	survey, AUTM, USPTO	linear regression, negative binomial regression	number licenses licensing income total number spin-offs number local spin-offs
Caldera & Debande (2010)	Spain	2001-2005	52 universities	RedOTRI technology transfer survey	linear regression	number university-industry R&D contracts income university-industry R&D contracts number licenses licensing income number spin-offs
Chapple et al. (2005)	UK	2001	50 universities	survey	DEA, SFE	number licenses licensing income
Foltz et al. (2000)	US	1991-1998	142 universities	AUTM, NSF	linear regression, negative binomial regression	number patents number patents in agricultural biotechnology citations weighted patent counts
Friedman & Silberman (2003)	US	1997-1999	83 research universities	AUTM, NSF, NRC, Milken Institute "Tech-Pole" Data	linear regression–system equations estimations	1. regression: number invention disclosures 2. regression: number licenses number spin-offs licensing income number licenses with equity number active licenses

Note: NRC: National Research Council, NSF: National Science Foundation, AUTM: Association of University Technology Managers, SFE: Stochastic Frontier Analysis, DEA: Data envelopment analysis

A-1 (continued): Overview of selected papers analyzing technology transfer performance

Authors	Country	Period	Sample size	Main Data Source	Statistical technique	Performance measurement (dependent variable(s))
Hülsbeck et al. (2013)	DE	2005-2007	29 universities	survey, interview data, GPO, Federal Office of Statistics, Center for University Development, German Patent Atlas, university websites	negative binomial regression	number invention disclosures
Lach & Schanker-man (2004)	US	1991-1999	102 universities	AUTM, NSF, NRC	linear regression	licensing income
Lach & Schanker-man (2008)	US	1991-1999	102 universities	AUTM, NSF, NRC	linear regression	licensing income
Link & Siegel (2005)	US	1991-1998	113 academic institutions	survey, AUTM, NSF; US BEA	SFE	number licenses licensing income
Powers (2003)	US	1991-1998	108 Research I and II institutions	AUTM, NRC	linear regression	number patents number licenses licensing income
Rogers et al. (2000)	US	1996	131 research universities	AUTM, NSF, NRC	correlation analysis	composite technology transfer score: number invention disclosures number U.S. patents number licenses/options number licenses/options yielding income number spin-offs licensing income
Siegel et al. (2003)	US/Canada	1991-1996	113 US universities	AUTM, NSF, US BEA, interviews	SFE, linear regression	number licenses licensing income

Note: NRC: National Research Council, NSF: National Science Foundation, AUTM: Association of University Technology Managers, SFE: Stochastic Frontier Analysis, DEA: Data envelopment analysis

A-1 (continued): Overview of selected papers analyzing technology transfer performance

Authors	Country	Period	Sample size	Main Data Source	Statistical technique	Performance measurement (dependent variable(s))
Siegel et al. (2008)	US/UK	2001	83 US universities, 37 UK universities	AUTM, survey in UK	SFE	number spin-offs number licenses licensing income
Sine et al. (2003)	US	1992-1998	102 universities	AUTM	negative binomial regression	number licenses/options
Thursby & Kemp (2002)	US	1991-1996	112 universities	AUTM, NRC	DEA, logit regression	number licenses amount industry sponsored research number patents number invention disclosures licensing income
Thursby et al. (2001)	US	1996	62 research universities	Survey	linear regression	number patents number licenses licensing income amount sponsored research tied to a license frequency of sponsored research included in a license
van Looy et al. (2011)	EU	2003	105 universities	survey, Web of science, EC Report on S&T Indicators, Eurostat, EPO Database	linear regression, negative binomial regression	number patents amount contract research number spin-offs

Note: NRC: National Research Council, NSF: National Science Foundation, AUTM: Association of University Technology Managers, SFE: Stochastic Frontier Analysis, DEA: Data envelopment analysis

A-2: Empirical results of determinants on technology transfer performance

	Indicator	Insignificant	Negatively significant	Positively significant
Regional demand for technology	R&D intensity / industry concentration	Chapple et al. (2005) [licensing income]	Hülsbeck et al. (2013)	Belenzon & Schankerman (2009)
		Siegel et al. (2003) [licensing income]		Chapple et al. (2005) [number licenses]
		van Looy et al. (2011) [number patents, amount contract research]		Foltz et al. (2000)
				Friedman & Silberman (2003)
				Lach & Schankerman (2004)
				Lach & Schankerman (2008) [stronger effect for private universities]
				Link & Siegel (2005)
				Siegel et al. (2003) [number licenses]
				Siegel et al. (2008)
				van Looy et al. (2011) [number spin-offs]
	economic activity (GDP)	Siegel et al. (2008)		
		Hülsbeck et al. (2013)		
	state support for higher education		Powers (2003) [number licenses, licensing income]	
	number of spin-offs in region/ entrepreneurial climate	Hülsbeck et al. (2013)		Powers (2003) [number licenses]
		Powers (2003) [number patents, licensing income]		
	venture capital	Powers (2003) [number patents]	Powers (2003) [number licenses, licensing income]	
		Siegel et al. (2008)		

A-2 (continued): Empirical results of determinants on technology transfer performance

	Indicator	Insignificant	Negatively significant	Positively significant
Quality and type of the technology produced by the academic institution	faculty quality	Caldera & Debande (2010) [licensing income, number spin-offs]	Caldera & Debande (2010) [number licenses]	Caldera & Debande (2010) [number R&D contracts, R&D income]
		Lach & Schankerman (2004)	Thursby & Kemp (2002)	Foltz et al. (2000)
		Lach & Schankerman (2008)		Friedman & Silberman (2003) [number invention disclosures]
		Thursby et al. (2001) [number licenses, number patents, number , amount sponsored research tied to a license]		Hülsbeck et al. (2013)
				Powers (2003)
				Thursby et al. (2001) [licensing income]
				van Looy et al. (2011)
	universities' research orientation	Belenzon & Schankerman (2009) [number spin-offs]		Belenzon & Schankerman (2009) [licensing income, number licenses, different directions]
		Lach & Schankerman (2004)		van Looy et al. (2011) [number patents]
		Lach & Schankerman (2008)		
		van Looy et al. (2011) [amount contract research, number patents]		
	university academic rank			Foltz et al. (2000)
				Sine et al. (2003)

A-2 (continued): Empirical results of determinants on technology transfer performance

	Indicator	Insignificant	Negatively significant	Positively significant
University institutional variables	presence of medical school	Belenzon & Schankerman (2009) [number spin-offs] Caldera & Debande (2010) [R&D income, number licenses, licensing income, number spin-offs] Chapple et al. (2005) [number licenses] Friedman & Silberman (2003) Lach & Schankerman (2008) Link & Siegel (2005) Powers (2003) Siegel et al. (2003) Sine et al. (2003) Thursby et al. (2001) [licensing income]	Anderson et al. (2007) [weak] Belenzon & Schankerman (2009) [number licenses] Chapple et al. (2005) [licensing income] Thursby & Kemp (2002)	Belenzon & Schankerman (2009) [licensing income] Caldera & Debande (2010) [number R&D contracts] Hülsbeck et al. (2013) Siegel et al. (2008) Thursby et al. (2001) [number licenses]
	private (vs. public)	Anderson et al. (2007) Belenzon & Schankerman (2009) [licensing income, number licenses] Caldera & Debande (2010) [licensing income] Friedman & Silberman (2003) Powers (2003) Siegel et al. (2003)	Belenzon & Schankerman (2009) [number spin-offs] Caldera & Debande (2010) [number R&D contracts, R&D contract income, number spin-offs]	Caldera & Debande (2010) [number licenses] Lach & Schankerman (2004) Thursby & Kemp (2002)
	land-grant university	Friedman & Silberman (2003) [number spin-offs, licensing income, number licenses with equity, number active licenses]		Friedman & Silberman (2003) (weak) [number licenses]
	presence of engineering school/polytechnic	Caldera & Debande (2010) [number R&D contracts] Powers (2003)		Caldera & Debande (2010) [R&D income, number licenses, licensing income, number spin-offs] Hülsbeck et al. (2013)

A-2 (continued): Empirical results of determinants on technology transfer performance

	Indicator	Insignificant	Negatively significant	Positively significant
University institutional variables	federal funding	Powers (2003) [number licenses, licensing income]		Foltz et al. (2000) Friedman & Silberman (2003) [number invention disclosures] Powers (2003) [number patents] Rogers et al. (2000)
	industry funding	Foltz et al. (2000) Hülsbeck et al. (2013) Powers (2003) [number licenses, licensing income] Sine et al. (2003)		Friedman & Silberman (2003) [number invention disclosures] Powers (2003) [number patents] Rogers et al. (2000)
	R&D funding from all sources	Lach & Schankerman (2008) [private universities]		Lach & Schankerman (2004) Lach & Schankerman (2008) [public universities]
	average faculty salary			Rogers et al. (2000)
	size	Hülsbeck et al. (2013) Lach & Schankerman (2008) [private universities] van Looy (2011) [spin-off activity]		Friedman & Silberman (2003) [number invention disclosures] Lach & Schankerman (2004) Lach & Schankerman (2008) [public universities] van Looy et al. (2011) [amount contract research, number patents] Caldera & Debande (2010)
	university science park	Caldera & Debande (2010) [number licenses, R&D contract income] Siegel et al. (2008)		Caldera & Debande (2010) [number R&D contracts, licensing income, number spin-offs]
	incubator			Siegel et al. (2008)

A-2 (continued): Empirical results of determinants on technology transfer performance

	Indicator	Insignificant	Negatively significant	Positively significant
Characteristics of the TTO	size	Caldera & Debande (2010) [licensing income]		Chapple et al. (2005) (decreasing return in scale)
		Hülsbeck et al. (2013)		Caldera & Debande (2010) [number R&D contracts, R&D contract income, number licenses, number spin-offs]
		Lach & Schankerman (2004)		Foltz et al. (2000) (decreasing return in scale)
		Lach & Schankerman (2008) [public universities]		Lach & Schankerman (2008) [private universities]
		Link & Siegel (2005) [licensing income]		Link & Siegel (2005) [number licenses]
		Siegel et al. (2003) [licensing income]		Powers (2003)
		van Looy et al. (2011) [amount contract research, number patents]		Rogers et al. (2000)
				Siegel et al. (2003) [number licenses]
				Siegel et al. (2008) (decreasing return in scale)
				Thursby et al. (2001) [number licenses]
				van Looy et al. (2011) [number spin-offs]
	age/ experience	Caldera & Debande (2010) [number licenses, licensing income, number spin-offs]	Chapple et al. (2005) [number licenses]	Caldera & Debande (2010) [number R&D contracts, R&D contract income]
		Chapple et al. (2005) [licensing income]	Siegel et al. (2008)	Friedman & Silberman (2003)
		Powers (2003) [licensing income]		Hülsbeck et al. (2013)
		Siegel et al. (2003) [number licenses]		Lach & Schankerman (2004)
				Lach & Schankerman (2008) [stronger effect for private universities]
				Link & Siegel (2005)
				Powers (2003) [number patents, number licenses]
				Siegel et al. (2003) [licensing income]

A-2 (continued): Empirical results of determinants on technology transfer performance

	Indicator	Insignificant	Negatively significant	Positively significant
Characteristics of the TTO	inventor's share of royalties	Caldera & Debande (2010) [number licenses]		Caldera & Debande (2010) [licensing income] Friedman & Silberman (2003) Lach & Schankerman (2004) Lach & Schankerman (2008) [strong effect for private universities, smaller and less precisely for public universities] Link & Siegel (2005)
	external IP expenditure	Chapple et al. (2005) [number licenses]	Link & Siegel (2005) [number licenses] Siegel et al. (2003) [number licenses]	Chapple et al. (2005) [licensing income] Link & Siegel (2005) [licensing income] Siegel et al. (2003) [licensing income]
	specialization in tasks	Caldera & Debande (2010) [number licenses, licensing income, R&D contract income, number spin-offs]		Caldera & Debande (2010) [number R&D contracts] Hülsbeck et al. (2013)
	incentives for TTO personnel	Belenzon & Schankerman (2009) [number licenses, number spin-offs]		Belenzon & Schankerman (2009) [licensing income]
	number of invention disclosures			Belenzon & Schankerman (2009) Chapple et al. (2005) Friedman & Silberman (2003) Link & Siegel (2005) Siegel et al. (2003) Sine et al. (2003) Thursby et al. (2001) [number licenses, number patents]
	invention disclosures per TTO staff		Sine et al. (2003)	

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