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Does inventor ownership encourage university research-derived entrepreneurship? A six university comparison

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ABSTRACT

This paper examines whether university ownership of inventions made by its personnel best serves the widely held social goals of encouraging technology commercialization and entrepreneurship. Using a hand-collected census of technology-based university spin-offs from six universities, one of which is the University of Waterloo and the only inventor ownership university in North America, we compare the number and type of spin-offs produced by these universities. We find suggestive evidence that inventor ownership universities can be more efficient in generating spin-offs on both per faculty and per R&D dollar expended perspective. We find that the field of computer sciences and electrical engineering generates a greater number of spin-offs than do our other two categories – the biomedical sciences, and the field of engineering and the physical sciences. In general, our results demonstrate that inventor ownership can be extremely productive of spin-offs. From these results, we suggest that governments seeking to encourage university invention commercialization and entrepreneurship should experiment with an inventor ownership system.

1. Introduction

When first introduced, new laws and practices attract great attention. However, if successfully diffused, they soon become normalized and treated as "natural" (Suchman, 1995; Tolbert and Zucker, 1983), becoming unquestioned routines (Nelson and Winter, 1982). This can lead to new governance models, which are, in fact, social creations shaped by various forces (Cyert and March, 1963; Davis and Thompson, 1994; Ocasio and Kim, 1999). This is the case with the current implementation of the Bayh-Dole Act in the U.S., which enshrined institutional ownership of university inventions. Despite recent questioning of the efficacy of the university ownership regime in commercializing inventions in the U.S. (Litan et al., 2007; Kenney and Patton, 2009) and increasingly in Europe (Geuna and Nesta, 2006; Fini et al., in this issue), faith in the efficacy of current university ownership regime for technology commercialization remains unshaken.

The conventional view is best illustrated by a 2010 report authored by the National Research Council (Merrill and Mazza, 2010: p. 58) stating, "arguments for the superiority of an inventor-driven system of technology transfer are largely conjectural. There is certainly anecdotal evidence of faculty dissatisfaction with the technology licensing office-dominated model as well as evidence of faculty entrepreneurial success independent of such offices, but there is no systematically collected evidence that inventors have knowledge and skills superior to those of technology transfer personnel and their service providers in the various components of IP acquisition, management, and licensing." This conventional wisdom has a powerful grip on the science policy debate. This conclusion is validated by the total adoption in the U.S. and widespread diffusion of the university ownership regime globally (see Fini et al., in this issue; Mowery and Sampat, 2005; So et al., 2008).

Despite increased questioning of the university ownership model, particularly in relationship to the growing interest in entrepreneurship, there has been little research comparing the university ownership regime with alternatives such as inventor ownership. In an earlier paper, we examined the faulty conceptual and theoretical political economic underpinnings of the current university ownership regime from an efficiency and effectiveness perspective (Kenney and Patton, 2009). This paper tests these contentions by measuring the numbers of direct university spin-offs at six universities, one of which, the University of Waterloo, Canada (hereafter Waterloo) operates under an unfettered inventor ownership regime. The results, though limited by having only one inventor ownership university, suggest that policy-makers desiring to foster entrepreneurship and local economic development should consider adopting an inventor ownership regime.

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2. Previous research and proposition development

In recent years the Bayh-Dole (BD) Act and its effect on university technology transfer and university-based entrepreneurship has received increasing attention from both academics interested in technology policy and policy-makers (for excellent summaries, see Rothaermel et al., 2007; O'Shea et al., 2008; Shane, 2004a). The dominant narrative accepts university ownership facilitated by the Bayh-Dole Act of 1980 (BD) as necessary for the commercialization of research results, and as the reason for the success of U.S. universities in commercializing inventions through entrepreneurship.[1]

The current university ownership regime is a governance model that accords with a particular belief structure about how rights and responsibilities should be allocated for commercializing inventions made at universities with Federal (and other) funding and how technology can be best commercialized. The research being commercialized is the result of public funding and conducted at tax-exempt institutions. Since the 1980s, particularly for public universities supported by state governments, local economic development has been recognized as an important goal (Lockett et al., 2005). Further, a central U.S. societal goal, since at least the Great Depression, has been the support of small businesses and particularly entrepreneurship.

The most common alternative to commercializing the technology through an entrepreneurial firm is to license the technology, and Thursby and Thursby (2007: p. 631) found licensing income to be the most important self-identified goal for technology licensing offices (henceforth, TLOs). For the TLO, licensing to an established firm is an attractive option because it can more easily pay upfront licensing fees and cover legal and other costs.[2] In cases in which the invention is licensed to an existing firm, the employment generated due to the license normally occurs at the firm's existing facilities, which may not be in close proximity to the university. Established firms licensing the technology are unlikely to have any allegiance or gratitude to the source university. Another pitfall is that an established firm may license a technology and never commercialize it for a variety of reasons, such as changing R&D goals, "banking" the patent for other motives, or a simple lack of motivation. This contrasts to a spin-off, whose future is based upon the technology and thus is compelled to attempt to commercialize the invention.

For many public universities economic development contributions have become an increasingly significant justification for state funding. Studies of university entrepreneurship show that certain universities report far higher rates of founding than others (Friedman and Silberman, 2003; Landry et al., 2006; Lockett and Wright, 2005; O'Shea et al., 2005). Almost always, university spin-offs are established in close proximity to the university (Breznitz, 2008; Shane, 2004a) and continue to cultivate strong ties with the university. In some cases, university spin-offs can be the seeds that result in the formation of an entrepreneurial ecosystem, as has been the case for biotechnology in the San Francisco Bay Area, Boston, and San Diego regions (Powell et al., 2002). One outcome of entrepreneurial success can be that the spin-off provides increased research funding for the local university's laboratories (Blumenthal et al., 1986; Dechenaux et al., 2009). Finally, successful entrepreneurs can be the source of donations. These results suggest that the benefit of spin-offs can be substantial for the source university.

Evidence from Europe and Japan suggests that university ownership is not vital for technology transfer, as most transfer in these nations has been to existing firms and thus does not directly encourage new firm formation (Carraz, 2008; Chapple et al., 2005; Geuna and Nesta, 2006; Valentin and Jensen, 2007). Both Audretsch et al. (2005) and Thursby et al. (2009) have shown that U.S. professors held a significant number of patents in their research field that were assigned to firms, even while they were university employees (see also Link et al., 2007; Markman et al., 2008; Siegel et al., 2003). Using a survey instrument, Fini et al. (2010) found that two-thirds of the firms established by university professors were not based on patented inventions or inventions disclosed to their university TLO. Building upon Lowe (2006), Kenney and Patton (2009) reason that the allocation of invention-ownership rights to the university TLO instead of the inventor installs an extra intermediary between the inventor and the market place. The empirical evidence of patenting and firm formation by university personnel outside the TLO, and an understanding of the role and operation of TLO in the university ownership regime suggest that an inventor ownership regime will generate greater technology-based entrepreneurship than will a university ownership regime. For these reasons, each of the following propositions tests the performance of Waterloo against the five university ownership institutions. Thus, in our initial and most general test, we propose:

P1. *Inventor ownership universities have a greater number of spin-offs than university ownership universities.*

It has long been common wisdom that the propensity and ease of establishing new firms differs by industry and, by extension, the academic research field. Despite this knowledge, the differences in invention, patenting, and spin-offs between academic research fields has not received significant attention with a few notable exceptions. For example, in an examination of TLO inputs and outputs Thursby and Kemp (2002: pp. 121–122) found that the biological sciences and engineering are more important to licensing activities than are the physical sciences. Moreover, universities with medical schools were less likely to be efficient in generating various outputs. For example, there has been remarkably little comparative cross-disciplinary research on university disclosures, patenting, licensing, or spin-off generation. In another study Thursby et al. (2009) distinguished to which types of organizations (university, unassigned, startup, or established firm) faculty assigned their patents. They found that the patterns of faculty assignment of patents differed by academic field. In fact, they found that both physical scientists and engineers were less likely to assign to the university than were biological scientists (Thursby et al., 2009: p. 21). The results with disclosures, licensing, and patenting suggest that academic field may have a significant influence on spin-offs, also. Our academic fields are not directly comparable with those of the previous papers because of our decision to separate EE&CS from the rest of engineering.

A substantial body of research suggests that the number of spin-offs from a university is conditioned by characteristics of universities such as quality, R&D expenditures, and number of faculty (Shane, 2004b). The academic status of universities and their respective departments has repeatedly been found to be important in terms of numbers of spin-offs (see, for example, DiGregorio and Shane, 2003; O'Shea et al., 2005; Stuart and Ding, 2006; Zucker et al., 1998). University and departmental prestige, measured by either the quality of science and engineering faculty (O'Shea et al., 2005) or by overall graduate school ranking (DiGregorio and Shane, 2003), is positively and significantly related to the number of spin-offs per year. Hence, we propose that:

[1] For a detailed discussion of the passage and early impacts of the BD Act, see Mowery et al. (2004) and Berman (2008).

[2] This is tempered by some recent research finding that universities increasingly are accepting equity in lieu of licensing fees (Feldman et al., 2002; Markman et al., 2005).

P2. *Inventor ownership universities will have a greater number of spin-offs than their status, as measured by rankings would suggest, but this will be conditioned by research fields.*

The positive relationship between research expenditures and the number of technology-based spin-offs has been repeatedly confirmed (Lockett and Wright, 2005; O'Shea et al., 2005; Powers and McDougall, 2005). The conversion of university R&D expenditures into concrete outcomes has received only limited research. One key study is by Thursby and Kemp (2002) and examines TLO efficiency in converting disclosures to licenses, patents, royalties, etc.; they do not measure efficiency in terms of direct spin-offs. As was the case with the previous proposition that drew upon Kenney and Patton (2009), we would expect that inventor ownership universities will spin-off a greater number of firms per R&D dollar, but that this will be conditioned by academic field. So, we propose:

P3. *Inventor ownership universities, on an R&D expenditure basis, will be more efficient at spinning-off firms than university ownership universities, but this will be conditioned by field.*

Because the institutional barriers to firm formation at inventor ownership universities are lower (Kenney and Patton, 2009), we would expect that they would spin-off a greater number of firms per faculty member than university ownership universities, but this will be conditioned by academic field.[3] Hence:

P4. *Inventor ownership universities, on a per faculty basis, will be more efficient at spinning-off firms than university ownership universities, but this will be conditioned by field.*

In university-regimes disclosure of inventions to the TLO is mandatory and universities can initiate litigation against any personnel that they believe have misappropriated their property. Because we have data regarding whether the spin-off licensed university technology, it is possible to compare licensing across universities. In an inventor ownership university it is not necessary to license technology; though Waterloo's Watco issues a license when an inventor wishes to use their services for patenting and marketing. For this reason, we expect licensing will be far lower at Waterloo, what is more interesting is to examine the likelihood that a spin-off will license by academic field. Thus, while we express the proposition, as a comparison between inventor and university ownership, the more interesting results will be the differences by field. So, the final exploratory proposal is that

P5. *In inventor ownership systems a lower percentage of spin-offs will license technology from the university, but this will be conditioned by field.*

3. The setting for the comparison

The Canadian and U.S. university systems share many institutional similarities and certain differences. At the macro political level, both nations are North American settler states experiencing high levels of immigration. Canada is an Anglo-Saxon common law nation (Black and Gilson, 1998). The 2008 per capita GDP, for Canadians was US$39,800, while in the U.S. it was US$47,000. For adults, the average years of schooling in the U.S. is 12 years and in Canada is 11.6. One significant difference between the two nations is that the U.S. spends 2.62% of GDP on R&D, while Canada spends only 1.94% suggesting that the U.S. government and firms have a greater orientation toward new technology development. Despite this difference, the macroeconomic similarities are quite striking. By nearly all relevant criteria, Anglophone Canada and the U.S. share strong similarities.

In terms of the entrepreneurial environment, the Global Entrepreneurship Monitor data shows that the U.S. and Canada were similar in terms of high-expectations entrepreneurship (Autio, 2007). In terms of the experience with and availability of venture capital, the U.S. was the first nation to establish and continues to have the world's largest venture capital industry. Canada was a fast follower as its first venture capital firms were formed in the early 1970s (Ross and Partners, 1972) making it the oldest venture capital industry outside of the U.S. and United Kingdom. In terms of per capita venture capital investment, the nations are roughly comparable. For example, in 2003 the per capita venture capital investment in Canada was $67.20; while in the U.S. it was $64.42. While Canada is much smaller than the U.S., in per capita terms, venture capital investment is comparable. Canadian universities have been the source of approximately 1000 spin-offs and of these 100 have been listed on public stock markets in Canada or the U.S. (Niosi, 2006).

Like the U.S., the Canadian universities are the major public institution responsible for conducting research and it is largely funded by government granting agencies. All major Canadian universities are publicly operated, as opposed to the mixed system in the U.S. For this reason, in this study all the U.S. universities are public. The U.S. universities are not located in particularly significant technology clusters, though Waterloo is located in a Canadian technology cluster. In Canada, which has no law equivalent to BD, each university has set its own policies regarding invention ownership and there has not been any convergence upon a single practice (see Atkinson-Grosjean, 2002; Hoye, 2006).[4] These similarities suggest that any differences in university entrepreneurship are not due to variation in the political and legal systems of the two nations.

3.1. The University of Waterloo

Since its founding in 1957, the University of Waterloo has emphasized interaction with industry (Bathelt and Hecht, 1990). At its inception, local business leaders advanced a proposal to establish a university to train engineers and technicians who were desperately needed for Canada's growing post-war economy. However, it soon altered its training-centric charter to emphasize research in engineering, the sciences, and mathematics, but later became a comprehensive university (Nelles et al., 2005). It also developed a 'co-operative program' offering students paid work in industry to get practical experience (University of Waterloo Website, 2010). As is true at the other universities in our database, the support for entrepreneurship at Waterloo is strong. Over the years, a strong entrepreneurial culture has emerged. For example, the co-operative program offers an entrepreneurship track. This emphasis upon industry linkages bears a certain resemblance to the land-grant mission of four of the five U.S. universities.

Canada has significant concentrations of high-technology activity in a number of locations, particularly its larger cities (Lucas et al.,

[3] The efficiency measures in P3 and P4 are based on spin-off counts, and do not capture all of the performance outcomes of university based startups, such as number of new products developed or jobs created. See Siegel and Wessner (forthcoming). Because our database includes the names and addresses of the firms, though the data was spotty, it was possible to examine firm growth in terms of employment and/or revenues. The difficulty is that the firms were established at different times. Not surprisingly, firms grew, failed, were acquired, acquired other firms, etc. over time, thereby affecting the employment results. For this reason, drawing any conclusions about impact was difficult and was limited to moments in time.

[4] With few exceptions, research on Canadian university spin-offs has not recognized that it has the most diverse set of university technology ownership regimes in the world and thus simple regressions across all Canadian universities or unadjusted comparisons across universities are missing an important variable (as an example of such an exercise, see Landry et al., 2006).

2009). But only in a "Technology Triangle" comprised of three cities, Waterloo-Kitchner, Guelph, and Cambridge does Canada have a concentrated high-technology agglomeration (Bathelt et al., 2010; Bramwell and Wolfe, 2008; Bramwell et al., 2008).[5] As previous research predicts, (Agrawal and Cockburn, 2003; Audretsch et al., 2005), nearly all of Waterloo's spin-offs were established in the vicinity of the university (Bramwell et al., 2008). The University of Waterloo is located at the core of the high-technology activity in the region (Xu and McNaughton, 2006).

From its inception, and unique among Canadian research universities, Waterloo adopted a policy that all inventions, not explicitly the property of a sponsor, were owned by the inventor, with the sole requirement that all inventions be disclosed to the university administration (Hoye, 2006). This placed responsibility for commercialization on the inventor, but ensured that conflicts of interest could be monitored. According to Bramwell et al. (2008: p. 105), "much of the university's commercialization and spin-off success is attributed to its intellectual property (IP) policy, which allows ownership of IP to rest with the creator, thus encouraging the individual (faculty or student) to commercialize the idea." Waterloo has been the most successful Canadian university in encouraging the formation of new firms by its faculty, students, and staff (Xu and McNaughton, 2006: p. 597).

To assist inventors, the University of Waterloo operates the Waterloo Commercialization Office (Watco),[6] with the mandate to assist any and all university inventors. Watco's total annual income has been about C$500,000. Its objective is not to secure returns; rather it is funded as an annual budget item with the goal of assisting in technology commercialization. If an inventor chooses to use Watco, the division of proceeds after patent processing fees is normally 25% for Watco and 75% for the inventor(s). In cases in which the inventor pays for the patenting Watco can be flexible on the percentage, particularly in cases of software inventions where there may be no patent costs. To further encourage spin-offs, Watco may provide royalty vacations. Finally, Watco advises spin-offs even when it does not have any direct stake (Inwood, 2010).

The successes of the University of Waterloo are underappreciated because, until recently, academic researchers simply used data provided by the local Association of University Technology Managers members that only reported the spin-offs using their offices. Recent research indicates that for U.S. universities, this database contains only one-third of all firms formed by professors (Fini et al., 2010). For this reason, AUTM data underreports the number of Waterloo spin-offs. For example, utilizing AUTM data Langford et al. (2006) found that University of Waterloo underperformed many other Canadian universities in numbers of patents issued and licensing fees collected. Using AUTM data, while easy, underestimates entrepreneurship and validates AUTM and university ownership as vital to technology commercialization.

3.2. The U.S. universities

At this time, every U.S. research university owns all inventions developed using their facilities.[7] This was not always the case as Stanford University, which has been the most successful of all U.S. universities in terms of high-impact entrepreneurship, converted to a university ownership regime in 1994. The University of Wisconsin had a policy giving professors ownership of all inventions made without federal monies and not encumbered by grant stipulations, though today this is a moot point because of the ubiquity of Federal support. Because the goal is to compare entrepreneurship at an inventor ownership university to university ownership universities, the differences in TLO operation at the five U.S. universities are not examined (for discussions of U.S. TLO operation, see Colyvas et al., 2002; Owen-Smith and Powell, 2001; Owen-Smith, 2005).[8]

4. Data collection and methodology

This paper utilizes a unique database of all technology-based spin-offs created by university-affiliated personnel at five U.S. universities and one Canadian university.[9] The universities are the University of Wisconsin, Madison (UWM); the University of Illinois, Urbana-Champaign (UIUC); the University of Michigan, Ann Arbor (UMAA); the University of California, Davis (UCD), the University of California, Santa Barbara (UCSB); and the University of Waterloo, Waterloo, Canada (Waterloo). This study examined 527 university spin-offs from these six universities between the years 1957 and 2009. Twelve spin-offs that did not fit readily into a firm classification were omitted from further analysis leaving 515 university spin-offs.

The U.S. universities were chosen for the following reasons. First, all of the universities are public. Second, each one is located in university towns simplifying the identification of local spin-offs and providing some control for their geographical location and the local ecosystem. The three Midwestern universities are located in the U.S. industrial Midwest as is the case with Waterloo's location in the Canadian industrial heartland. Third, each of the U.S. universities is research-oriented, as is Waterloo. According to the Shanghai Jiao Tong University ranking, all of the U.S. universities are ranked overall in the top 50 universities worldwide, and all of them are ranked in the top 25 universities worldwide in at least one general field of study. In global ratings terms, the U.S. universities are superior to Waterloo. Fourth, though all U.S. universities practice university ownership, the technology licensing organizations differ in their organizational location and operational characteristics. In general, these five U.S. universities are comparable to the University of Waterloo with respect to size, academic ranking, and location outside of a globally recognized entrepreneurial region.

There has been a proliferation of classification schemes for university research spin-offs (see, for example, Carayannis et al., 1998; Pirnay et al., 2003). Fini et al. (2010) classify spin-offs on the basis of whether they were established on the basis of patented technology and whether the technology is owned by the inventor's university. Nicoloau and Birley (2003) separate firms into what they term as: orthodox, which are firms whose technology and inventors spin-off from the university; hybrid, which are firms whose technology is licensed but the inventor remains a university employee while having a relationship with the firm; and spin-offs, which are firms with which the inventor has no connection. In contrast, Wright et al. (2007) uses the market goals of the spin-offs and identifies three ideal types of university spin-offs: venture capital-backed spin-

[5] For a general discussion of where Canada's technology firms and characterization of each region, see Doutriaux (2003). Colapinto (2007) possibly somewhat hyperbolically compared Waterloo with Silicon Valley and Route 128, though, in large measure, this may be due to the success of Waterloo spin-off Research in Motion, producer of the Blackberry.

[6] For those interested in understanding how a university can operate a technology commercialization office in an inventor ownership regime, the Watco website (http://www.research.uwaterloo.ca/watco/index.asp) provides an excellent introduction.

[7] Some believe that at the University of Wisconsin, Madison professors own their own inventions. This is not the case even when using their own funds in campus laboratories; all inventions are automatically assigned to the juridically separate Wisconsin Alumni Research Foundation.

[8] The University of Wisconsin's WARF has received the most attention, see, for example, George (2005).

[9] All of the universities in this study are public institutions. Other qualitative studies of TLOs have included private universities. See Siegel et al. (2004).

Table 1
Summary of university attributes.

Attribute description	Spin-offs Number of spin-offs, 1957–2010	Academic ranking 2010 SJTU ranking	R&D expenditures* $ millions, 2005–2008 average annual	Faculty size Total BMS, CS&EE, EPS faculty
UWM	140	17	792	2195
UMAA	88	22	724	3193
UIUC	72	25	462	2120
UCD	40	46	563	2038
UCSB	37	32	163	559
Waterloo	138	151–200	95	963

Source: Various, Waterloo faculty size data is for 2011, while for U.S. Universities the data is for 2006.
* Total for BMS, CS&EE, and EPS; all other R&D expenditures are excluded.

offs; prospector spin-offs, based on technology with less immediate market potential; and lifestyle spin-offs, which are established by academic personnel with more of a consultancy orientation. Most U.S. studies of university spin-offs, with the exception of Fini et al. (2010), focus on data that is most easily collected, i.e., licensing, which is particularly significant in biotechnology and faculty inventions disclosed to the university TLO. Using Waterloo as a case study, Bathelt et al. (2010) categorize spin-offs based on whether the university "sponsored" the research or whether they were university-related in that the university in some more indirect way figured in the firm's formation. While the classification schemes often include student spin-offs, most of the empirical research does not include them due to the difficulty of identifying them.

In our database, which is a census not a sample, only de novo, high-technology university spin-offs were included. To be considered a high-technology university spin-off a firm had to fulfill three criteria. The firm had to be de novo, it had to be high technology, and it had to be founded by university personnel. To be recognized as de novo the firm could not be a spin-off from an existing firm or be a subsidiary or branch operation. All de novo firms receiving venture capital, as identified in Thomson VentureExpert were included. Very small firms of just a few employees providing services or engaged in consulting were excluded from consideration, as were all exclusively retail establishments.

Second, the firms had to be technology-based. This removed from consideration firms in apartment management and farming along with small technical consulting firms established by university personnel. If the spin-off was, for example, writing software algorithms for larger firms, then it would be included. Also, internet website firms targeting the local region were excluded. In contrast, software product spin-offs were included as were internet firms that grew to be large enough to have a significant web presence or receive venture capital. The reasons for these exclusions were to capture high-potential entrepreneurship and exclude firms such as those Wright et al. (2007) identifies as "life-style" firms.

A number of techniques and sources were used to assemble the firm database. First, all venture capital investments in the county within which the university was located were downloaded. Second, university's websites, particularly the technology transfer office, business school, and engineering websites were searched. At a number of universities, individuals or organizations, such as local development agencies and business organizations, have compiled lists of firms. In some cases, the business press was a valuable source of information. Finally, interviews with local key persons were conducted.

Each firm's description was examined to ensure that it conformed to our criteria. The list was then provided to individuals and entrepreneurs in the region to ascertain if there were missing firms. Data collection was terminated when no new firms were found and interviewees said they believed the database was complete. Despite our confidence regarding the database's completeness, it is likely to be missing the smallest firms formed prior to 1980, especially those no longer extant. In determining which firms were high technology, and what type of technology category most accurately described them, the authors relied on a consensus in classification by other sources whenever possible. These sources included descriptions on the firm's website, in the local business press, from the university technology transfer office, or a local business association. Each decision for inclusion was made by one of the co-authors and validated by the other.

Finally, to be classified as a university spin-off, a firm had to have been founded by at least one individual affiliated with the university during or immediately prior to establishing the spin-off. For all firms in the database an attempt was made to identity the founders through web searches.[10] At the time of the firm's founding, the status of the founders' relationship with the university was determined. This relationship was determined from the founder's biography, which was usually derived from the internet. A firm founded by an individual who had other employment between the time they left the university and founded the firm would not be classified as a spin-off.[11] Firms that were established based on a university technology license were excluded if no firm founder was affiliated with the university. An important reason for excluding such "license-only" firms is that examination of a number of these firms indicated that often they were established on the basis of a number of licenses from a variety of organizations, and so establishing a causal linkage between the firm formation and a particular university license is not self-evident.

The licensing data itself in the case of UIUC, UCD, UCSB, and Waterloo was provided by the university's technology licensing office. In the case of UWM the data was extracted from the Insite (2010) database maintained by the UWM School of Business. The UMAA data was collected and provided by then University of Michigan professor Arvids Ziedonis and by the UMAA technology licensing office.

All spin-offs were assigned to 23 different categories and these were aggregated to three. The category of biomedical sciences (BMS) includes all spin-offs involved in biotechnology and firms selling inputs to biotechnology firms, all firms involved in the provision of medical services and supplies, including medical instruments, and all veterinary and agricultural biology firms. Computer science and electrical engineering (CS&EE) includes all firms involved in computers, electronic components, information technology, internet applications, semiconductors, software, telecommunications, and wireless. Engineering and physical sciences (EPS) includes all spin-offs involved in engineering with the exception of electrical and biomedical engineering. It also

[10] If the founder or founders of a firm could not be identified, or if there was insufficient information to determine the employment background of the founder, these firms were not included in the database.

[11] The time elapsed between the time an individual, usually a student, left the university and founded a spin-off was determined by the individual's biography. If this time period was 1 year or less, and there was no information indicating that the individual was employed in the interim, then it was classified as a university spin-off.

includes all firms involved in environmental applications, materials, robotics, and scientific instruments. Finally, it includes the physical sciences.

4.1. Variable description

Academic ranking was one of our independent control variables. While there have long been rankings of U.S. graduate programs, it has only been within the last decade that cross-national ranking of universities and programs has been undertaken. Currently there are two widely cited global rankings of universities; the Shanghai Jiao Tong University (SJTU) rankings starting in 2003, and the Times Higher Education rankings begun in 2004 (for a critique of these rankings, see Saisana et al., 2011). Because the SJTU rankings emphasize academic performance and are more comprehensive than those provided by Times Higher Education, they are utilized in this study. Unfortunately, the SJTU rankings have only been implemented recently and they began ranking by subject only in 2009. This means contemporary rankings must be used, though the data in this paper is historical. While the rankings are treated only as indicative, they are still informative.

R&D expenditure data was another independent variable. This data is available for both U.S. and Canadian universities. For U.S. universities, the National Science Foundation (NSF, 2009) survey of research and development expenditures of universities and colleges was used. In Canada, no similar source of data was located so it was compiled from the R&D statistics provided by the four main Canadian federal agencies. R&D funding classifications from the major Canadian federal agencies comports with the U.S. system. However, these four agencies did not account for all of the government R&D funding that Waterloo received from all sources. In Canada the provinces, in this case Ontario, provide an important share of the total R&D funding a university receives. In 2008, for example, these four agencies provided just 52.6% of the total R&D the university received.[12] To adjust for this undercount of R&D across disciplines, each R&D category in 2008 was adjusted upward by a factor of 1.901 (1 divided by 0.526), so that all individual R&D categories, BMS, CS&EE, EPS, and other R&D areas not included in this study, would sum to the total 2008 R&D amount. This adjustment is based on the assumption that the total R&D the university receives is distributed among disciplines in the same proportions as the R&D received from national agencies. An adjustment factor was calculated for each year and applied to all Waterloo R&D expenditure categories, providing us with estimates of Waterloo R&D expenditures for BMS, CS&EE, and EPS.

Faculty size in the relevant academic fields was the final independent variable collected. The U.S. data was obtained from the National Research Council's data base assessment of doctoral programs in the U.S. (NRC, 2010) and is for 2006. For Waterloo comparable data was unavailable so in 2011 each academic department website was accessed and all regular faculty members were counted.

5. Descriptive statistics and basic results

The six universities can be ranked according to four characteristics; spin-offs, academic ranking, R&D expenditures, and faculty size. As a general observation, one would expect that all four of these characteristics would be positively correlated. What is immediately apparent is that, in general terms, Waterloo is smaller and less highly ranked than its U.S. comparison group (see Table 1), except in terms of numbers of spin-offs.

Among these six universities the UWM has the longest history of promoting technology transfer going back to 1925 with the establishment of the Wisconsin Alumni Research Foundation (WARF). And yet, nearly all of the spin-offs produced by these universities were founded after 1975. Prior to 1975 and in the post World War Two period, the UWM produced 11 spin-offs, while Waterloo and UIUC produced two, and the UMAA and UCSB had one each. Waterloo's first spin-off occurred in 1970, while the first UCD spin-off occurred in 1975. The cumulative number of all spin-offs by each university through the year 2009 is shown in Fig. 1.[13] The relative performance in terms of spin-offs has generally held over time. From the beginning of our database, UWM and Waterloo have excelled in terms of the number of spin-offs generated. It was only in the early 1990s that UMAA and UIUC accelerated thereby separating themselves from UCD and UCSB.

In keeping with P1, the universities also perform differently when the spin-offs are categorized into three broad fields (see Table 2). In terms of the absolute numbers of spin-offs, UWM and Waterloo have been the source of the greatest number, followed by UMAA and the UIUC and then UCD and UCSB, which were the source of the fewest spin-offs. When divided into different technological fields, UWM had the greatest number of BMS spin-offs, while Waterloo was the leader in both CS&EE and EPS. There is another interesting observation from Table 2, namely with the exception of UWM and UCD, at the other universities CS&EE outperformed the other fields in absolute numbers of spin-offs. For example, CS&EE accounted for nearly half (46.2%) of all spin-offs. BMS had 169 spin-offs, or 32.8% of the total, while EPS comprised 108 spin-offs, 21.0%

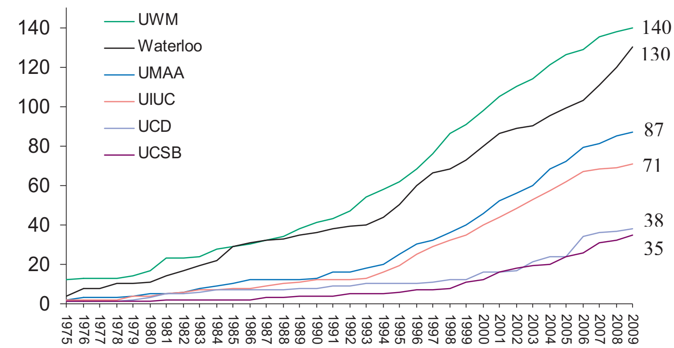

Fig. 1. Cumulative number of spin-offs by university, 1957–2009.
Source: Authors' database.

Table 2
Spin-offs by university and technology category, 1957–2010.

	BMS	CS&EE	EPS	Total
UWM	78	43	19	140
UMAA	37	38	13	88
UIUC	8	40	24	72
UCD	26	6	8	40
UCSB	12	17	8	37
Waterloo	8	94	36	138
Total and % by class	169	238	108	515
	32.8%	46.2%	21.0%	

Source: Authors' database.

[12] Total R&D funding for Waterloo was obtained from Research Infosource Inc. (2011), a private Canadian consulting firm which reports total R&D funding for all Canadian universities based upon all publicly available data. This data was then compared to the official University of Waterloo Annual Performance Indicators report and the differences were negligible.

[13] The university count of total spin-offs in Fig. 1 differs slightly from that reported in Table 2. It was not possible to establish a founding year for 13 spin-offs, and so these spin-offs were not included in Fig. 1. In addition, one spin-off from UCD was founded in 2010, and so this spin-off was excluded as well.

of the total. There are likely a number of reasons for this that include the low-cost of software firms, the ability for students to create such firms, and the availability and interest of VCs in the field.

From this perspective, in terms of spin-off generation Waterloo performs in the first tier. However, from Fig. 1 it can be seen that both UWM and Waterloo were benefited by a long history of entrepreneurship. In the case of Waterloo, graduate students have been a major contributor in terms of firm establishment. If, as much of the literature suggests, entrepreneurship leads to positive feedback loops, this may explain some measure of the significant lead these two universities enjoy. At UIUC and UMAA, there was an acceleration in entrepreneurship in the early 1990s that separated them from the two Universities of California that only a decade later appear to have become more entrepreneurial. This data provides significant support for P1 as Waterloo is roughly on par with UWM which, interestingly enough, had an earlier history of inventor ownership that has now been abandoned.

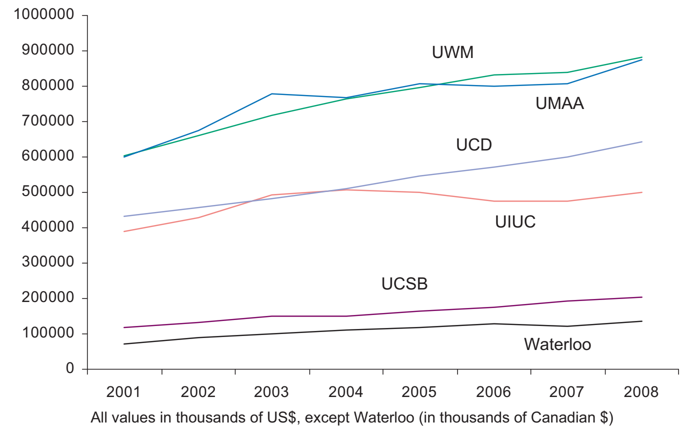

Fig. 2. Total R&D from all sources: 2001–2008.
Source: National Science Foundation (2009) and Research Infosource Inc. (2011).

5.1. Academic ranking and spin-off performance

Academic status has been found to be highly correlated with disclosures, patenting, and spin-off firms. Unfortunately, there are no cross-national ranking systems that correlate directly with our technological areas. In Table 3 the SJTU ranking for 2010 are displayed. In the overall rankings, Waterloo was significantly inferior to the U.S. group.[14] However, as is well known, universities excel in different fields. For example, UWM, UIUC, UCD, and UMAA rank particularly high in the life sciences. This is not surprising because three have colleges of agriculture (UWM, UCD, UIUC), and three have medical schools (UWM, UCD, UMAA), while UIUC has a College of Medicine, but not a medical school.[15] UIUC, UMAA, and UCSB are particularly strong in CS&EE and PSE.

The general evidence suggests that academic status is correlated with the number of startups. For example, the strengths of UWM and UCD are in BMS, whereas UIUC has its spin-off strength in CS&EE and EPS. UMAA is quite balanced in rankings and this is reflected in its performance by field. This is also true within the University of California system, where UCD's strength in BMS has led to a greater number of spin-offs, while UCSB's strength is particularly evident in CS&EE. There are anomalies. CS&EE at UWM has quite low ratings, but, in terms of spin-offs it trails only Waterloo, being roughly equal to the far higher-status UIUC. For example, UCSB, though having a relatively low-ranking in the life and agricultural sciences has 12 spin-offs, but this can be explained by a significant number of biomedical device spin-offs for its College of Engineering.

Waterloo is clearly different. It has relatively low status, but great success in spinning off firms. Waterloo's strength was in the fields in which it had its highest rating in engineering and computer science – and the performance was remarkable as it had more than twice as many CS&EE startups as any of the other universities. It also has more startups in EPS than any other university.

As expected and in conformance with P2, overall ranking has a positive relationship with spin-offs. Moreover, as predicted this relationship holds at the field level. But most interesting is the finding that, as P2 predicted, inventor ownership is a very powerful effect that overcomes ranking. If one controls for academic ranking, then P2 is strongly supported and provides evidence that inventor ownership can have a very strong impact on spin-off generation.

5.2. R&D funding and spin-off performance

The literature, not surprisingly, finds that the number of spin-offs and total R&D expenditures are correlated. Because of the difficulty in collecting cross-national data, we only have data for the years 2001 through 2008. In Fig. 2 the R&D expenditures for these universities for all categories, not just BMS, CS&EE, and EPS, are shown. For the entire period, with the exception of the UIUC after 2004, R&D expenditures gradually increase. Moreover, the relative ranking of the universities does not deviate substantially over the 9-year period with the exception of UIUC falling behind UCD. This was likely due to a decline in Department of Defense funding for university research even as NIH continued to expand (Benhamou et al., 2009). What is remarkable is that across the four largest universities with large biological research programs the R&D expenditures per spin-off were roughly comparable. UCSB, which is more engineering-oriented, had far lower R&D expenditures per spin-off, while Waterloo was only one-third of the UCSB level. This supports P3.

When R&D expenditures are separated by field, there are significant differences (see Table 4), but these should be interpreted with care due to the relatively small numbers in each category. The most significant difference in terms of costs per spin-off was between the biomedical sciences and computer sciences. At the field level Waterloo was more efficient in every field confirming P3, but across all of the universities CS&EE yielded far more spin-offs per increment of R&D expenditures – essentially the difference is an order of magnitude. Two of the three universities with large agricultural research operations, UCD and UIUC, had high ratios of cost per startup. The amount of funding BMS received compared to the other fields was remarkable and is the result of NIH's allocation of an increasing share of federal extramural funding. Since the bulk of these research expenditures are from public sources, this suggests a significant policy orientation toward BMS research funding.

5.3. Faculty and spin-off performance

The final and crudest measurement for entrepreneurial activity is the sheer number of faculty, and ceteris paribus it would be expected that the number of faculty and spin-offs would be positively correlated. The universities differed dramatically in terms

[14] We acknowledge that global academic excellence ranking systems for universities are somewhat arbitrary. In just 7 years, using the same criteria, the overall ranking of the UIUC went up 20 places and the UWM went up 10, while UCSB fell 6 places and UCD fell 10 places. Variation in ranking is even more dramatic across ranking entities using different criteria, which should remind us that such academic rankings are useful but imprecise instruments.

[15] Just three of these universities have a medical school; the UWM, UMAA, and UCD. Therefore it would not be expected that universities without a medical school would rank highly in the subject field of clinical medicine and pharmacy.

Table 3
2010 Shanghai Jiao Tong University global academic rankings, overall and selected technology categories.

	Overall world ranking	Natural sciences and mathematics	Eng, technology and computer science	Life and agricultural sciences	Clinical medicine and pharmacy	Computer science
UWM	17	17	23	11	20	52–75
UMAA	22	21	7	24	8	18
UIUC	25	23	4	18	n.a.	13
UCSB	32	19	15	51–75	n.a.	44
UCD	46	46	46	21	n.a.	50
Waterloo	151–200	n.a.	52–75	n.a.	n.a.	76–100

Source: Shanghai Jiao Tong University (2010).

Table 4
R&D expenditures by university and technology field, 2005–2008 inclusive, $ millions with R&D expenditures per spin-off in parentheses.

	BMS	CS&EE	EPS	Total
UWM	2199 (274.9)	104 (20.8)	866 (216.5)	3169 (186.4)
UMAA	2056 (228.4)	193 (32.2)	647 (323.5)	2896 (170.4)
UCD	1810 (452.5)	57 (14.3)	386 (77.2)	2253 (173.3)
UIUC	642 (642.0)	440 (88.0)	766 (127.7)	1847 (153.9)
UCSB	91 (15.2)	173 (43.3)	388 (194.0)	652 (54.3)
Waterloo	71 (71.0)	97 (6.1)	212 (26.5)	381 (15.2)
Total R&D	6869	1064	3265	11198
2005–2008 spin-offs	29	40	27	96
R&D$ per spin-off	(236.9)	(26.6)	(120.9)	(116.6)

Source: Authors' database.

of the numbers of faculty by field and overall (see Table 5). As was the case with R&D expenditures, the four universities with large BMS faculties were less efficient overall in generating spin-offs. However, UWM was the most efficient on a per faculty basis among the large universities in generating BMS spin-offs. While on a per faculty basis in BMS, Waterloo was not particularly efficient in generating spin-offs. UCSB's efficiency was driven by the spin-offs being from biomedical engineering, thereby expressing the engineering efficiency rather than that of biology departments.

Table 5
University and technology field and number of faculty, 2006 except Waterloo which is 2011 faculty per spin-off in parentheses.

	MBS	CS&EE	EPS	Total
UWM	1385 (173.1)	155 (31.0)	655 (163.8)	2195 (129.1)
UMAA	1790 (198.9)	172 (28.7)	1231 (615.5)	3193 (187.8)
UCD	1396 (349.0)	99 (24.8)	543 (108.6)	2038 (156.8)
UIUC	1023 (1023.0)	276 (55.2)	821 (136.8)	2120 (176.7)
UCSB	148 (24.7)	89 (22.3)	322 (161.0)	559 (46.6)
Waterloo	232 (232.0)	165 (10.3)	566 (70.8)	963 (38.5)
Total faculty	5974	956	4138	11,068
2005–2008 spin-offs	29	40	27	96
Faculty per spin-off	(206.0)	(23.9)	(153.3)	(115.3)

Source: National Research Council (2010) and calculated by authors from University of Waterloo departmental websites.

In overall terms, being concentrated in CS&EE and EPS allowed UCSB and Waterloo to appear most efficient on a per faculty basis. On a per faculty basis, Waterloo, once again, was the most efficient on a per faculty basis, thereby lending support to P4. One factor that did not seem to affect Waterloo's performance was that its departments (and thus faculty) were not particularly highly ranked, therefore there were likely less star scientists (see, for example, Zucker et al., 1998). In comparative terms, UCSB was particularly strong in star scientists having four science Nobel Prize winners, though this did not improve their total number of spin-offs.

5.4. *The relationship between R&D expenditures, faculty, and spin-offs*

To reasonably compare spin-offs across universities it is necessary to not only control for the field of technology, but to control for the capacity of a university to generate spin-offs. This section presents the data visually so it is possible to compare faculty size and R&D expenditures simultaneously. For each industry, the figures display the inverse of the ratios reported in the previous section, i.e., the ratio of spin-offs divided by R&D is plotted on the *X*-axis while the ratio of spin-offs over faculty is plotted on the *Y*-axis. It is important to note that the *X*- and *Y*-axis scales differ by figure due to the differences between technology fields. Movement away from the origin represents superior performance in terms of spin-offs generated per R&D dollar or faculty member.

For the BMS, as Fig. 3 shows, all of the universities except UCSB are grouped together. UCSB stands out for efficiency because it has relatively few faculty in the biomedical sciences and a relatively low level of R&D funding in this area, but most importantly because its spin-offs were in medical devices; a comparatively low-cost sub-

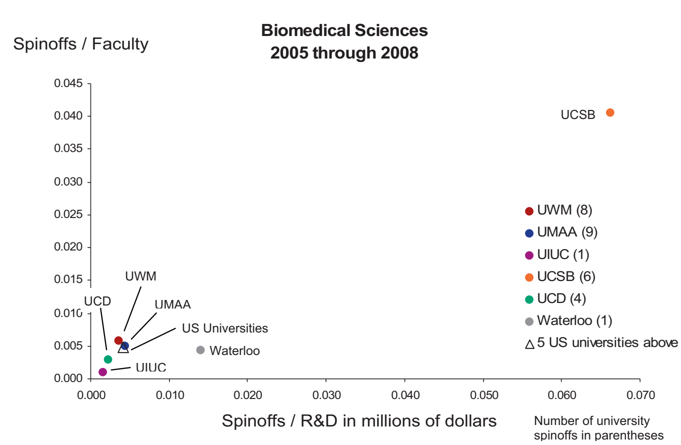

Fig. 3. Biomedical sciences 2005 through 2008.
Source: Author's database.

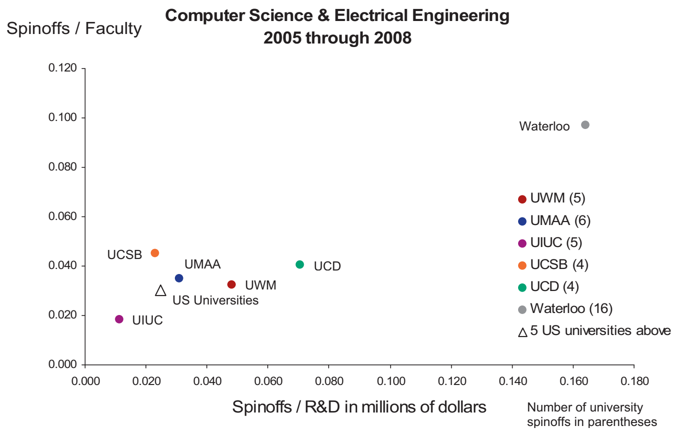

Fig. 4. Computer science and electrical engineering 2005 through 2008.
Source: Author's database.

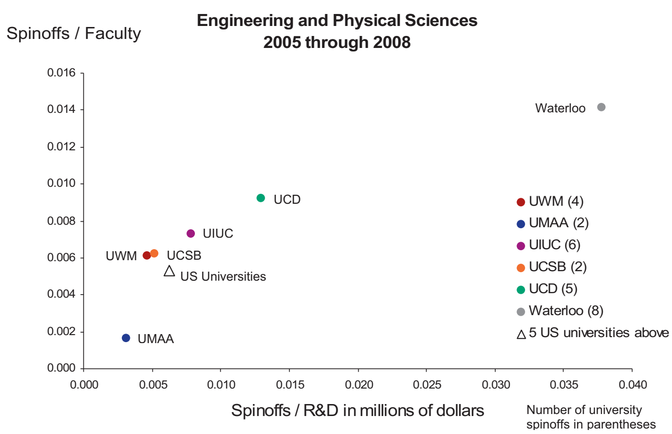

Fig. 5. Engineering and physical sciences 2005 through 2008.
Source: Author's database.

sector of the biomedical sciences that came from the engineering college.[16]

In CS&EE, as Fig. 4 indicates, Waterloo's performance is remarkable, and though this is in part driven by the large number of graduate student spin-offs the difference is dramatic. Waterloo's performance also holds in EPS. As Fig. 5 indicates, the University of Waterloo boasts dramatically better performance than the U.S. universities on a per R&D$ and faculty member basis. In EPS, inventor ownership appears to be far more efficient in generating spin-offs than university ownership.

In terms of efficiency regarding the total numbers of spin-offs, Waterloo dramatically dominates all of the U.S. comparison universities, though UCSB also performs well in spin-offs per dollar of R&D expenditures and per faculty (see Fig. 6). This result provides some support Thursby and Kemp's (2002) finding that TLOs at smaller universities seemed to be more efficient. These figures demonstrate how much more efficient Waterloo was and reiterate the support for P3 and P4.

[16] UC Santa Barbara spun off four medical devices firms. Had these been counted as engineering spin-offs rather than biomedical spin-offs the relative performance of UC Santa Barbara would have declined in biomedical sciences but increased substantially in engineering and physical sciences. In either event its relative standing in total spin-offs would remain unchanged.

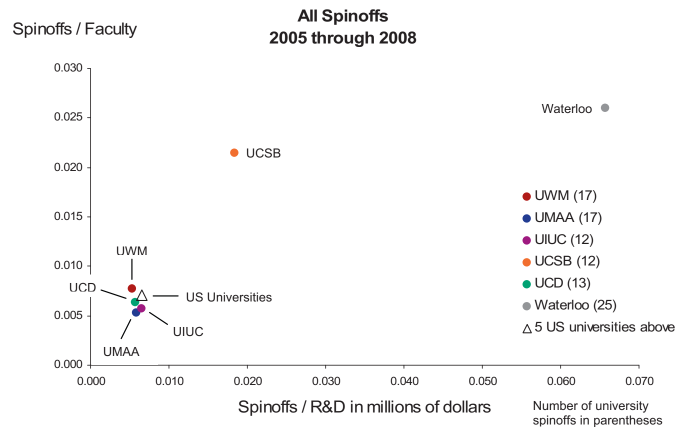

Fig. 6. All spin-offs 2005 through 2008.
Source: Author's database.

5.5. University licensing and entrepreneurship

In the university ownership regime, the rules vary as to which persons affiliated with the university must disclose their inventions made while undertaking R&D on campus to the TLO. At most universities, disclosures and mandatory transfer of rights to the inventions is required from all employees, visiting scholars, and graduate students. At these institutions, inventors wishing to commercialize inventions they developed on campus must receive a license from the TLO. Obviously, at inventor ownership universities there is no requirement to secure a license. This section explores whether there is a difference in startups licensing between inventor and university ownership regimes. There is reason to believe that the rate of licensing would vary by discipline for a number of reasons and it is interesting to consider whether the pattern of variation differs by ownership regime. As Table 6 shows, Waterloo spin-offs had the least number of licenses, thereby confirming P5.

Licensing is particularly significant in biotechnology as is the high level of faculty disclosure of inventions to the university licensing office. As might be expected, the BMS had the highest proportion of spin-offs (46.7%) with university licenses. Interestingly, though based on a very small number, at Waterloo BMS spin-offs were more likely to use the TLO and thus take a license. As Table 6 shows, the lowest proportion of licensed spin-offs is in CS&EE where only 18.1% are licensed. EPS is in between with 31.5% of spin-offs being licensed. Overall licensing seems to be the greatest at the three Midwestern universities, lower at UCD and UCSB,[17] and very low at Waterloo where only five out of a total of 138 spin-offs had university licenses. These results highlight the problem of relying upon AUTM data to measure technology-based university startups and, in particular, for Waterloo with its inventor ownership system. In public policy terms, this guaranteed underestimation may not serve U.S. universities well at a time when public support for universities is at low ebb.

6. Discussion

Despite the widespread interest, only recently has there been any experimentation with the institutional arrangements and obstacles to university-based entrepreneurship. Our results demonstrate that inventor ownership has a positive effect on

[17] In the case of the two Universities of California initially all TLO functions were centralized in the University of California Office of the President. They were later decentralized to the campuses, so there may be an institutional memory problem with underreporting of licensing in earlier cases.

Table 6
Number of university spin-offs and percentage licensed by university and technology category, 1957–2010.

	BMS		CS&EE		EPS		Total	
	Total spin-offs	% licensed	Total spin-offs	% licensed	Total spin-offs	% licensed	Total spin-offs	% licensed
UWM	78	47.3%	43	14.0%	19	36.8%	140	35.7%
UMAA	37	67.6%	38	39.5%	13	38.5%	88	51.1%
UIUC	8	87.5%	40	35.0%	24	58.3%	72	48.6%
UCD	26	30.8%	6	33.3%	8	37.5%	40	32.5%
UCSB	12	8.3%	17	29.4%	8	25.0%	37	21.6%
Waterloo	8	12.5%	94	1.1%	36	8.3%	138	3.6%
Total	169	46.7%	238	18.1%	108	31.5%	515	30.3%

Source: Authors' database.

entrepreneurship. It is remarkable that a relatively small Canadian university, though admittedly CS&EE-oriented, could perform so well. P1 proposed that inventor ownership universities would generate a greater number of spin-offs than university ownership universities. While UWM had the greatest number of spin-offs, if this was controlled for number of faculty, R&D expenditures, or global ranking, then Waterloo exhibited superior performance in terms of spin-offs. Among the four largest universities, UWM was superior on nearly every entrepreneurship metric. It is interesting to speculate if this was in any way linked to its earlier history of supporting inventor ownership. In summation, our data indicates that inventor ownership as a policy, with or without using controls, out-performs university ownership in terms of encouraging entrepreneurship.

Our results agree with those of earlier research in that higher-status universities have a greater propensity to generate spin-offs and that this relationship holds at the technological field level. However, the results also suggest that inventor ownership is a powerful intervening variable that can mitigate the role of status. This result is of great importance because it suggests that universities and policy-makers aiming to encourage technology transfer through entrepreneurship may be able to increase the performance of relatively low-status universities by loosening their intellectual property licensing regimes.

The existing literature suggests ceteris paribus that R&D expenditures and the number of spin-offs are positively correlated. In terms of the simple efficiency indicator of R&D expenditures per spin-off, Waterloo was superior to the U.S. universities, thereby confirming P3. What was possibly more interesting was the dramatic difference in efficiency in spin-off generation by field. BMS spin-offs were an order of magnitude more expensive on a per spin-off basis. Also, large agricultural research operations seemed to increase the cost per spin-off for two universities, which is possibly a function of the difficulty of creating startups in the plant sciences. So the results confirm that inventor ownership appears to have efficiency benefits in converting R&D expenditures to spin-offs. As was the case with academic ranking, absent an ownership-regime effect, R&D expenditures are correlated with numbers of spin-offs, but it is also possible that smaller universities may also have an efficiency benefit. Here again, ownership regime has a very powerful effect.

In terms of spin-offs per faculty, our smallest universities, Waterloo, was the most successful, but UCSB was quite close. Among the four largest universities, UWM was the leader. Again, there was a dramatic difference in the number of spin-offs on a per faculty member basis with CS&EE generating roughly one order of magnitude more spin-offs than BMS when examined across all universities. Overall the results once more suggest that inventor ownership can have a positive impact on the propensity of university personnel to establish spin-offs. A final interesting observation is that the three most successful spin-offs from our universities; Research in Motion (Waterloo), Netscape (UIUC), and PayPal (UIUC), were all established by CS&EE students.

As expected, Waterloo spin-offs had far fewer licenses than the U.S. universities. When considered across technology fields, the lowest percentage of licenses were in CS&EE where only 18.1% of the spin-offs secured licenses. BMS had the greatest percentage of licenses (46.7%) with EPS in the middle (31.5%). In CS&EE, many of the spin-offs are in software, where there are more student spin-offs and there is less likely to be a "paper trail" of laboratory notebooks. Also, CS&EE spin-offs are less likely to need physical facilities such as laboratories, thereby diminishing the need to maintain a linkage to the university. Both Waterloo and UCSB had particularly low licensing percentages in BMS, but at both universities the BMS spin-offs included a number of biomedical device firms that usually require less costly facilities than do biopharmaceutical spin-offs. These results also suggest that the utility of intermediaries such as a TLO may vary by discipline. A TLO or other skilled intermediary with significant resources may be more valuable to a biopharmaceutical firm than a software firm. The data on Waterloo suggests that this may be true as BMS had the highest percentage of licenses. This lends credence to the perception that TLOs concentrate their proprietary efforts in the biopharmaceutical field because this is where their leverage and potential contributions to spin-offs are the greatest. While only speculation, it suggests that even in inventor ownership cases, particularly those where the biomedical fields are strong, inventors will choose to use a TLO – provided, of course, it is perceived as competent and operating as a facilitator and not regulator.

7. Conclusion

These research results are tentative and subject to limitations. The greatest limitation is that Waterloo is the sole North American pure inventor ownership university. Other variables such as the local culture, university leadership, and TLO operation may have influenced our results.[18] In regards to the differences in levels of entrepreneurship by fields, different classifications would have affected the comparisons. However, given the striking differences, the results would have remained substantially the same. Our definition of a spin-off was extremely rigorous in terms of the firm having to be technology-based and the exclusion of the smallest firms, though, here again, we believe the relative results would not have changed.

Despite these caveats our results are striking. They suggest that more research and policy experimentation would allow a more scientific policy-making process to be undertaken. This examination of the entire population of technology-based spin-offs from six universities showed that the inventor ownership regime strikingly dominates the better funded, more highly rated, and much larger university ownership universities. Remarkably, the only university that had a history of inventor ownership, UWM, was Waterloo's

[18] With regard to influence of local and university culture, see, for example, Kenney and Goe (2004) and Bercovitz and Feldman (2008).

most significant competitor. The argument that Waterloo's success is because it is not as highly rated as the other universities and thereby has less interest in maintaining the highest academic standards is dubious due not only to UWM's example, but also to the fact that Stanford operated in an inventor ownership regime until 1994, as was the case for University of Cambridge in England until 2003. At the very least, the results show that in terms of entrepreneurial activity, inventor ownership can overcome disadvantages including academic ranking, volume of R&D expenditures, and faculty size.

The ability of Waterloo to spin-off new firms matches UWM and exceeds the other U.S. universities even as it has received less R&D support and has done so with fewer faculty. Moreover, this ability to generate spin-offs has not been confined to just a few areas such as computer science, software, or internet applications, but is evident across a broad range of technology fields. This occurred in a Canadian legal and financial system that, while very similar to that of the U.S., is not as optimized for the support of high-opportunity entrepreneurship, thereby making Waterloo's performance all the more remarkable.

The value to society of university spin-offs is hard to estimate, but there can be no doubt that policy-makers globally are concerned about this issue and there have been a proliferation of programs at the national, sub-national, and individual university level to improve research translation (Roberts and Malone, 1996; Breznitz et al., 2008). This is being recognized by some universities, as the introduction to this issue suggests in its discussion of the new North Carolina spin-off licensing initiative (University of North Carolina, 2011). More recently, the University of Missouri has loosened its ownership restrictions on student-developed spin-offs. While half-way steps, they suggest a growing awareness of the importance of spin-offs for regional development and technology transfer.

If it is accepted that entrepreneurship is important for economic development and that this is a desirable social goal, then the social good would be served by reducing obstacles within the parameters of protecting the overall university as an institution from issues such as conflicts of interest. Waterloo accomplishes this by requiring that all professorial linkages with firms be declared. The Waterloo example suggests that universities can improve their technology transfer activities dramatically by moving to more inventor control-centric policies and procedures. Entrepreneurship and technology transfer has repeatedly been identified as a U.S. policy goal, however organizationally universities have erected barriers to achieving this goal. Inventor ownership is a simple and unequivocal measure to assist this process. Waterloo, though only a single case, suggests that it can be successful.

Our results should be welcomed by the National Research Council, as they provide the first empirical test of the ability of differing ownership regimes to encourage technology commercialization through entrepreneurship. Though based on a single observation, these results suggest inventor ownership can be successful and is remarkably efficient economically. It also suggests that in the U.S., there is a cognitive capture mistaking the current institutional configuration as a "natural" order; the TLO-centric perspective has framed nearly all the thinking about entrepreneurial technology transfer about university-affiliated personnel becoming entrepreneurs. The results presented here suggest that broader thinking about, and experiments with, the types of invention ownership regimes is long overdue.

Since our database includes student spin-offs, our results also invite speculation about the role of students in university, entrepreneurship, and technological progress. In our database, the most successful spin-off was Waterloo's Research in Motion, which has become a large and influential firm. Arguably, the next two most influential and successful firms were Netscape and PayPal (both later acquired). All three firms shared two characteristics: (1) they were founded by students, and (2) they were in the information technologies. Only Netscape licensed technology from the university. This suggests that university students are a largely under-studied source of entrepreneurial university spin-offs (see Wennberg et al., in this issue and Astebro et al., 2011 for studies of university graduates and startups). Student spin-offs may be overlooked because they are difficult to identify or because they are often in the information technology fields within which patenting and TLO involvement is less significant. Our data collection methodology is one method of overcoming these obstacles.

Universities operating under an inventor ownership system can successfully commercialize campus inventions and encourage entrepreneurship even in the North American environment where the dominant ideological position is that TLOs are necessary for success. Because there are so few pure inventor ownership universities Waterloo is only an example, which is not only a smaller and less highly ranked university, but also is heavily weighted toward engineering and does not have a medical school. Despite these handicaps, it performed exceptionally well in encouraging entrepreneurship. A corollary to this view is that TLOs cannot operate in an inventor ownership regime when in fact Waterloo has a successful TLO. The Waterloo TLO, due to professorial ownership, operates as a service organization with an unconflicted mission of assisting inventors in commercializing their inventions.

This paper goes some way in ameliorating the National Research Council's concern that there was a lack of evidence on the efficacy of an inventor-driven system of technology transfer (Merrill and Mazza, 2010: p. 57). While the case of Waterloo certainly does not prove that inventor ownership is a superior system, no single example could do so, it is evidence that an inventor-driven system of technology transfer can perform very well. At the very least it suggests that inventor ownership is an alternative to the current university intellectual property regime, and that the discussion has moved beyond anecdotal evidence and conjectural arguments.

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