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Can universities profit from general purpose inventions? The case of Canadian nanotechnology patents

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ABSTRACT

The lack of control over downstream assets can hinder universities' ability to extract rents from their inventive activities. We explore this possibility by assessing the relationship between invention generality and renewal decisions for a sample of Canadian nanotechnology patents. Our results show that general purpose inventions enjoy a longer legal life. Although private sector organizations renew their patents at a higher rate than universities, the gap between the two sectors decreases as invention generality increases. However, there is little indication that the most general purpose inventions owned by universities survive for longer than the ones owned by private sector organizations.

1. Introduction

Facing decreasing public funding, universities are asked to become entrepreneurial and to learn how to profit from their innovative activities (Etzkowitz, 1998; Mowery et al., 2002). The markets for technology then become the natural space where universities should apply their entrepreneurial zeal (Arora et al., 2001). Interestingly, the markets for technology can lead to the emergence of firms that specialize in the creation of general purpose technologies (Bresnahan and Gambardella, 1998). Given that universities are especially proficient in producing these types of inventions (Trajtenberg et al., 1997), a large literature interested in the implementation of technology transfer best practices has thrived over the previous years (Thursby et al., 2001; Debackere and Veugelers, 2005; Lach and Schankerman, 2008; Rothaermel et al., 2007). The focus of the technology transfer literature has mainly been on the conditions under which universities can improve their bottom line from innovative activities. The focus of this literature is therefore to compare universities between each other. However, the crucial question of whether universities can profit *as much as* private sector organizations from their inventions has received less attention. If universities cannot generate enough profits from their inventive activities, the academic enterprise paradigm can end up being a dual failure: one the one hand, the problem of decreasing public fundings remains unsolved, and on the other hand, basic research risks being under-performed.

The main answer to this question comes from the theoretical underpinnings of the markets for technology framework. In this framework, the vertical integration of upstream and downstream assets by a single firm is linked to the nature of the firm's innovative activities or knowledge assets (Bresnahan and Gambardella, 1998). On the one hand, vertical integration of upstream and downstream activities is optimal for the owner of a "special purpose" invention. This means that a university that owns a special purpose invention will be better off acquiring downstream assets. Because this will incur *(forward) integration costs*, a university will profit less from a special purpose invention than a firm that already owns specialized downstream assets. "General purpose" inventions, on the other hand, favor the vertical separation of upstream and downstream activities. As a result, a vertically integrated firm that owns a general purpose invention will be better off disintegrating. This will incur *(forward) disintegration costs*, rendering the general purpose invention less profitable to the vertically integrated firm than to a university.

Various studies indicate that general purpose inventions result from basic and risky exploratory research (Trajtenberg et al., 1997; Rosenkopf and Nerkar, 2001; Fleming, 2001). Universities thus seem to be fit for markets for technology: given the type of "strategic

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factors" they own (namely scientists), universities have a competitive advantage in producing general purpose inventions and the markets for technology, by favoring upstream general purpose technology suppliers, allow universities to profit from their competitive advantage.

The above description is, however, devoid of any frictions. It turns out that institutional distance with the private sector (Foray and Lissoni, 2010), the quasi-exclusive reliance on licensing as a source of revenue (Shane, 2004b), as well as weaker bargaining power due to lack of complementary assets (Sakakibara, 2010) can represent serious barriers to the appropriation of benefits from inventive activity. Can savings in disintegration costs associated with general purpose inventions surmount these *competitive disadvantages* and allow universities to occupy the markets for technology? In this paper, we answer this question by testing whether the relationship between a patent's generality and its renewal can be moderated by whether the patent owner is a university or a private sector organization.

We analyze a sample of Canadian nanotechnology patents registered in the US. Our method consists of analyzing the link between a patent's renewal decision with the interaction of its assignee's institutional form (i.e. whether it is a private sector organization or a university) and its generality. By thereby linking the actual diffusion of a patent to its renewal, we are able to see which of the two sectors is more able to benefit from inventions that have in fact realized their technological potential. That is, we are not interested at the problem of cross-institutional knowledge diffusion, but rather in testing whether there are differences between universities and firms in the ability to benefit from inventions that have in fact spread over many technological areas. Our results show that an invention's generality can be associated with a longer legal life. We also find that private sector organizations renew their patents at a higher rate than universities. While the renewal gap between university and private sector organizations diminishes with the generality of the invention, we de not find evidence for universities being able to profit more from general purpose inventions than private sector organizations.

The remainder of the article proceeds as follows: Section 2 explains the theoretical framework and hypotheses underlying our study; Section 3 presents the data and methodology; Section 4 presents our results and Section 5 concludes.

2. Theoretical framework and hypotheses

2.1. Markets for technology and the entrepreneurial university

The markets for technology allow the division of innovative and commercial labor between firms (Arora et al., 2001; Arora and Gambardella, 1994). With this reduced need for the vertical integration of inventing and manufacturing activities into one firm, small technology specialists can have their businesses modeled around the commercialization of new knowledge (Gambardella and McGahan, 2010).

However, this vertical separation of downstream and upstream players requires strong appropriability regimes without which the upstream player cannot extract the downstream firm's surplus and vertical integration will prevail (Bonanno and Vickers, 1988; Arora et al., 2001; Arora and Fosfuri, 2003). Given the intricacies associated with knowledge transfer between opportunistic profit maximizing firms, property rights over knowledge assets become central in this framework. One can thus assume that markets for technology can function well in industries in which patenting can be associated with strong appropriability regimes (Levin et al., 1987).

A salient feature of the markets for technology is the prevalence of upstream suppliers who license out general purpose inventions (Gambardella and McGahan, 2010). These inventions have broad applications and are the foundations of subsequent special purpose inventions (Bresnahan and Trajtenberg, 1995; Trajtenberg et al., 1997). Because general purpose inventions can be licensed out to many downstream firms that are potentially competing in distant product markets, firms who produce knowledge-based assets are able to capture greater rents from their innovative activities (Gambardella et al., 2007; Gambardella and McGahan, 2010). We thus make the following first hypothesis:

Hypothesis H1. As generality increases, organizations are more able to capture profits from their inventions.

2.2. Market frictions, (dis)integration costs and Invention generality

A major difference exists between private and public sector organizations in terms of their respective capabilities to appropriate returns from innovation: public sector organizations, such as universities, can only rely on licensing to commercialize their inventions (Shane, 2004b).[1] This implies that universities can only generate revenue by competing in the markets for technology. Private sector organizations, on the other hand, have the possibility to integrate activities in both markets for technology and for products.[2] As it turns out, licensing patents can be a costly contractual process (Caviggioli and Ughetto, 2013). This can give an advantage to private sector organizations which will have their inventions receive payments through internal organization while economizing on the transaction costs that would be associated with licensing patents.

Due to reasons associated with their historical mission as providers of basic knowledge, universities can be viewed as firms lacking complementary assets (Bercovitz and Feldman, 2007). From the perspective of the complementary assets framework (Teece, 1986), this means that universities will often fail to appropriate full returns from their inventions. Admittedly, universities will not suffer from the "rent dissipation" effect associated with licensing out technology to the competition, a matter that will increase their willingness to license out their inventions (Arora and Ceccagnoli, 2006; Arora and Fosfuri, 2003). However, this does not automatically mean that universities can profit more from innovative activities than downstream-asset-owning firms unless the rent dissipation effect erodes rents in their entirety. Indeed, private sector organizations can opt not to license their invention when the revenue effect is, at the margin, superior to the rent dissipation effect (Arora and Fosfuri, 2003). This is an option that universities do not have.

An important aspect of profiting from innovation is the ability to bargain effectively during contract negotiations (Gans et al., 2002). Control over specialized complementary assets can give more bargaining power during contract negotiation (Ceccagnoli and Jiang, 2013). This means that universities are more often bargaining with a *weaker hand* (Sakakibara, 2010).

One can also consider institutional heterogeneity as a source of distance between potential suppliers and buyers of technology. Institutional norms and reward systems can be different between public and private sector organizations, which can lead to problematic

[1] Of course, universities can launch spinoffs which they can even own in their entirety, a process that can be viewed as a form of forward integration. It turns out that Shane (2004a) reports relatively low rates of spinoff creation to invention disclosures.

[2] We are assuming that all private sector organizations are indeed integrating ctivities in both product and technology markets, that is they are not 'non-producing entities'. In the case of defensive or strategic patenting by producing entities, this assumption recognizes that the firm will indirectly impute private benefits associated with the strategic gain of holding the patent, although these patents will never be developed and sold into products. However, the assumption is unrealistic for the case of private sector non-producing entities. We thus conjecture that observations in line with our following hypotheses will not necessarily hold in the case of non-producing private sector organizations.

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interactions (Dasgupta and David, 1994; Stephan, 1996; Foray and Lissoni, 2010). The fact that inventions stemming from public research has the reputation of being embryonic, combined with buyer concerns about the involvement of academics in further commercial development, can lead to greater reluctance by private sector organization to license patents owned by universities (Jensen and Thursby, 2001).[3] This could come down to an *invented-in-academia* bias which can lead to lower demand, if one assumes that the greater share of demand in the markets for technology comes from private sector organizations. Institutional heterogeneity can also lead to higher transaction costs simply because greater distance separates norms and rules in the private and the public sector, and thus greater effort has to be spent to converge to an agreement during the contracting phase. The bulk of demand for technology coming from the private sector, this could mean higher transaction costs for the licensing of academic patents.

Given the above arguments, we make the following hypothesis:

Hypothesis H2. On average, universities are less able than private sector organizations to capture profits from their inventions.

The above sources of competitive disadvantage are exacerbated by the fact that industry structure relates with the nature of technology. Inventions that are of special purpose nature lead to the emergence of vertically integrated firms (Bresnahan and Gambardella, 1998). Therefore, firms that do not own downstream assets will undergo forward integration as long as the benefits of integration are greater that its costs. In the case of universities, this can typically mean launching a university spinoff. As a consequence of the incurring of these forward integration costs, universities will be less able to profit from special purpose inventions than innovative firms that do own downstream assets.

When dealing with general purpose inventions, the separation of upstream technology specialists and downstream manufacturers becomes the prominent vertical structure (Bresnahan and Gambardella, 1998). This means that large incumbent firms will be better off vertically disintegrating from their downstream activities as they produce inventions of increasing generality. Disintegration, however, does not come without costs (Baye et al., 1996). This implies that universities have a competitive advantage in that they do not have to bear the costs of disintegration given that they do not own downstream assets. Therefore, as invention generality increases, the costs associated to the sources of competitive disadvantage that universities have are overtaken by savings in disintegration costs. We thus posit the following hypothesis:

Hypothesis H3. As generality increases, universities are relatively more able than private sector organizations to capture profits from inventions.

While savings in disintegration costs increase with invention generality, so do losses of benefits due to the institutional sources of competitive disadvantage. For instance, owning complementary assets can be associated with better ability to deter entry in the face of radical competence-destroying change (Tripsas, 1997; Rothaermel, 2001). Ownership of complementary assets can also be linked to greater financial profitability for incumbents when the creator of important patents are firms coming from other industries (McGahan and Silverman, 2006). In other words, entry by firms that generate important inventions but who do not control complementary assets is more likely going to contribute to the financial well-being of the incumbents. This factor puts universities at a competitive disadvantage when commercializing general purpose inventions.

Owning downstream assets can also foster the adoption and possibly the profitability of a general purpose invention in the following manner: the upstream technology supplier uses its knowledge to integrate the general purpose invention with one or many downstream application sectors for which it owns complementary assets, which in turn creates positive externalities if one agrees that subsequent application sectors will be able to benefit from the learning process that was accumulated during the initial integration. Simultaneously, the act of downstream integration by the technology supplier can by itself have positive feedback by contributing (through learning by using) to the improvement of the quality of the general purpose invention which in turn increases demand from other application sectors (Gambardella, 2002; Thoma, 2009). Again, universities are put in a position of disadvantage compared to private sector organizations.

Regarding transaction costs, it is reasonable to claim that transaction costs increase with technology generality due to greater appropriability hazards (Cassiman and Valentini, 2009). Because general purpose inventions must be integrated with different "application sectors", each requiring their own set of specialized complementary assets, multilateral coordination and contracting between agents with asymmetric information will ensue (Bresnahan and Trajtenberg, 1995). From an organizational perspective, interdependency between actors poses coordination challenges (Gulati and Singh, 1998). Mayer and Nickerson (2005) argue that technological complexity makes interfacing between various partners more difficult, and thus encourages in-sourcing. Complex interdependency can thus be a source of increasing coordination costs in technology transfer contracting. Not owning downstream assets and thus not being able to internalize at least some of these costs,[4] universities can have a greater share of their rents be eroded. Successful coordination and contracting under conditions of vertical and horizontal externalities is also a matter of capabilities (Bresnahan and Trajtenberg, 1995). Here again, the historical mission of universities might *not* endow them with the capabilities that (large) corporations have in terms of managing large-scale complex technological developments (Maine and Garnsey, 2006).

Hypothesis H4. Overall, private sector organizations are more able than universities to capture profits from their inventions.

3. Methodology

3.1. Data

Given that most important source of revenue for universities comes from licensing, patent data are a natural choice of analysis. Patents give exclusive rights to an inventor for a limited time in exchange of the public disclosure of the invention. Patents

[3] Colyvas et al. (2002) deny the validity of such claims regarding the commercial readiness of university inventions and argue that a large share of these technologies have always been adopted in science-based industries.

[4] One should note that the propensity to license out technology is weaker as the downstream operations of an organization are larger (Arora and Ceccagnoli, 2006; Arora and Fosfuri, 2003). Even very large firms, however, cannot control all the complementary assets needed to enter all application sectors, and will thus not be able to internalize all the transaction costs associated to licensing. However, the coordinating effort will be smaller if downstream assets are controlled in at least one application sector, which would most probably be the firm's core downstream capability in which case licensing could be ruled out due to rent dissipation effects. In other words, given a general purpose invention with N application sectors, a private organization with downstream assets in K sectors*could*in some cases have to coordinate only $N-K$ sectors, whereas a university *will*always has to coordinate all N sectors.

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are granted to inventions that are novel, non-obvious and useful, and therefore can be viewed as indicators of technological change and innovative activity (Basberg, 1987; Acs and Audretsch, 1989; Griliches, 1990; Archibugi, 1992).[5] We analyze a sample of nanotechnology patents granted by the USPTO to Canadian assignees or inventors. Because it can be classified as an emerging science-based industry, nanotechnology is an interesting testbed for comparing private–public sector capabilities in appropriating benefits from inventions. Emerging science-based technologies are almost always created within universities and are then transferred to the industry. Universities are thus expected to be on the frontier of knowledge production and therefore more competitive in these emerging science-based fields. Canadian universities are also an interesting subject of study because, unlike some of their American counterparts, they all fall within the jurisdiction of public higher education institutes. Yet, the US is Canada's greatest economic partner, which endows Canadian organizations with familiarity with many US institutions.

Our sample was obtained by performing a Boolean extraction on patents containing nanotechnology related keywords and clustering similar patents based on their co-citations (Barirani et al., 2013).[6] Because this method only takes the main network component into account, we use the resulting nanotechnology sample for training a *K*-NN classifier that would subsequently classify the nanotechnology patents that are not connected to the main network component. Classification is based on tokenized patent titles and abstracts. Our sample contains 789 patents obtained from 1990 to 1997 for which we have extracted information regarding their grant date, inventors, number of claims, forward citations and renewal decisions[7] until 2009. Technology transfer offices (TTO) can be viewed as being part of best practices in terms of commercializing university inventions. Information about the existence of a fully developed TTO within universities is gathered from the 2015 Association of University Technology Managers Activity Survey (AUTM, 2015).

3.2. Explained variable

USPTO policies dictate that patent owners must pay maintenance fees at the 4th, 8th and 12th years of a patent's legal life. Failing to pay these fees leads to the loss of the exclusivity conferred by the patent, in which case the owner cannot prevent others from using the invention anymore. Patent renewal can be related to the firm's expectation of future private returns associated with withholding the patent (Pakes and Schankerman, 1984). We do not interpret patent renewal as a sign of revenue streams but as a more general form of expected private benefits by the owner of the patent. In fact, even strategic patenting that does not intent to lead to new product development can bring benefits to its owner. If these benefits are expected to be greater than the costs of renewal, then the patent will be kept alive. This holds for university patents that are filed for the mere purpose of *showing off* technological prowess. Again, universities will renew these patents if they expect the benefits of signaling inventive capabilities to be greater than the renewal costs.[8] We use information regarding patent renewals at the 4th, 8th and 12th years (represented by binary response variables *RENEW4*, *RENEW8* and *RENEW12* respectively) as the dependent variables: patents that have not been renewed at years 4, 8 and 12 are said to have died at years 4, 8 and 12 respectively; patents that have been renewed at year 12 will live their full legal lifespan and their death is never observed.

3.3. Explanatory variables

According to USPTO regulations, applicants have the obligation to cite all related sources of knowledge that have led to the invention, but they are not legally obliged to perform prior art search. In essence, it is incumbent upon USPTO examiners to make sure that all relevant sources are properly cited (Meyer, 2000). Because of the thorough process of examination with which citations are added to a patent, Jaffe et al. (1993) argue that citations represent knowledge spillovers generated by patents. This view has somehow been nuanced given the fact that applicants can cite other patents strategically and that examiners can add citations that are not always relevant to the invention (Meyer, 2000; Cockburn et al., 2002).

Other studies have observed that examiner citations represent the largest percentage of self-citations (Alcácer and Gittelman, 2006; Alcácer et al., 2009). Technological and geographical distance between the citing and cited patents also increased the likelihood of the citation being added by an examiner (Criscuolo and Verspagen, 2008). Hegde and Sampat (2009) show that examiner citations are better predictors of patent renewal than applicant citations. From these perspectives, examiner citations can also be viewed as a smoothing process that ensures that most of the relevant prior art is cited (Meyer, 2000; Von Wartburg et al., 2005; Azagra-Caro et al., 2011).

Patents that are subsequently cited in different technological classes are believed to be general purpose (Trajtenberg et al., 1997). Patent generality has been positively associated with private benefits (Maurseth, 2005; Palomeras, 2007; Bessen, 2008; Serrano, 2010; Fischer and Leidinger, 2014; Giummo, 2014). One should note that, given the inclusion of prior art requirement, forward citations are independent from renewal decisions by the patent assignee: it is still possible for patents to be cited even when they have not been renewed by their owners.

By adapting the Herfindahl–Hirschman Index, Trajtenberg et al. (1997) use the information about a patent's forward citations' US classes to measure its generality. Given a patent with n forward citations falling into m classes, the degree G with which the

[5] Patents however do not represent the whole range of inventions that are created as secrecy or lead time is often used as an alternative way of appropriating returns from innovations (Levin et al., 1987). Also, various studies point out that the majority of patents have little economic value (Allison et al., 2004; Moore, 2005). Patenting can be seen as "lottery tickets" where patent holders can never be sure of the value of their patent (Lemley and Shapiro, 2005). Furthermore, patents are sometimes used as strategic devices (such as for defensive purposes or "trolling") which implies that they will not always translate into new product development (Hall and Ziedonis, 2001; Gallini, 2002 ; Reitzig et al., 2007). Nevertheless, we will assume that organizations will patent an invention when they expect the private benefits of obtaining a patent will be greater than its costs. The advantage of proceeding in this way is that*all*benefits that an organization expects from the ownership of a patent will be included in the patenting decisions. For instance, a university that patents merely to signal technological ability will take those benefits into account when deciding to patent or not.

[6] More detail can be found in the Appendix regarding the data collection method.

[7] Information regarding renewal decisions and Small Entity Status are obtained from the USPTO Patent Maintenance Fees Events File which contains records of renewal events for patents granted from September 1, 1981 to present. The file can be found at https://www.google.com/googlebooks/uspto-patents-maintenance-fees.html.

[8] It can be worthwhile to further discuss that benefits from patenting need not be the same for different institutions (e.g. universities can be patenting for reputation or signaling purposes although this can turn out to be the case for private sector organizations as well). Signaling motives can nevertheless lose their value if patents are not renewed: after all, producing patents that are never renewed can be hardly justified as signaling anything more than the allocation of resources to paperwork. Indeed, it is well understood by practitioners that patents do not equate commercial value. Knowing this, technology transfer offices tend to avoid a*patenting for the sake of patenting*strategy. Thus, commitment (at least through renewal) to patented technologies is more likely to confer meaningful signal about the technological prowess of an organization.

patent's subsequent use spans technological disciplines, and thus its generality is:

$$G = 1 - \sum_{i=1}^{m} \left(\frac{C_i}{n}\right)^2 \tag{1}$$

where C_i is the number of forward citations that fall within class *i*. As the value for of *G* gets nearer to one, forward citing patents are spread more evenly among the *m* classes, which means that the patent's use is not focused to one discipline.

For each patent in our sample, we compute generality through Eq. (1) by taking forward citations received for years 0 to 4, 0 to 8 and 0 to 12 starting from the patent's grant year. These values are represented by dependent variables *GENERALITY4*, *GENERALITY8* and *GENERALITY12* respectively.

We account for the sector of activity (private or public) by examining patent assignees. Patents are classified based on whether they are owned by private sector organizations or by universities. We use the dummy variables *PRIVATE* to indicate whether the assignee is a private sector organization and *UNI* to indicate whether the assignee is a university. Public research institutes are thus the omitted group.

3.4. Control variables

The scope of patent claims determines the monopoly power bestowed to its owner by defining the main novel features of the invention (Merges and Nelson, 1990). Applicants have an incentive to claim as much as possible while examiners must narrow down the scope of the patent before granting it (Lanjouw and Schankerman, 2004). The number of claims can therefore be used as an indication of a patent's scope and quality (Tong and Frame, 1994). Variable *CLAIMS* is a measure of the number of claims granted to the patent.

One can add that the legal protection offered by patents is imperfect in practice because a patent's scope delineated by its claims can be circumvented and litigation does not guarantee repair of rights (Levin et al., 1987). For certain types of technologies, however, patents offer better protection. In the case of discrete technologies, such as pharmaceuticals, biotechnology and organic chemicals, patents are efficient for intellectual property protection and are less often used for strategic reasons (Levin et al., 1987; Merges and Nelson, 1990; Cohen et al., 2000; Hall and Ziedonis, 2001). In these industries, inventing around is more difficult because it is relatively easy to show that a competing product is infringing upon the patent's claims (Merges and Nelson, 1990). For firms that possess patents, appropriability regimes are thus strong in these industries. Within nanotechnology, the subfield of nanobiotechnology can be categorized as one offering mainly discrete technologies. As a result, patents can be associated with a strong appropriability regime in this subfield.

With more than 266 patents Xerox Corporation is the leading patent holder in our sample. This company's practices will be taken into account through a dummy variable named *XEROX*.

Time can have various effects on patent renewal practices. Industries go through different stages. As they mature and innovative activities take a cumulative turn, uncertainty associated to incremental innovations, which represent the bulk of the innovative effort, is lowered. Firms are thus expected to have a higher rate of patent renewal than in the early days where many failures can occur. In emerging industries, acceleration in the introduction of novel technologies can also lead to a faster rate of obsolescence which will also impact a firm's decision to renew. We control for this factor by using patents grant years, which are represented by the year dummies *Y1991* to *Y1997*. The omitted dummy is therefore *Y1990*.

The increasingly complex nature of high technology products obliges teamwork (Wuchty et al., 2007). Team size can thus be viewed as a sign of commitments to greater resources, which implies a certain level of expectation from the organization's point of view (Sapsalis et al., 2006; Liu, 2014). This could in turn have an impact on the general perception about an invention as well as the willingness to extend the *ex post* learning period. Since many advantages can be associated with being part of the inventors list, it is reasonable to assume that only those who bring distinctive skills to the table will be able to negotiate a place among the inventors' list. Larger teams can thus be associated with larger skill sets. We thus use the number of listed inventors, which is represented by *NBINV*, as a proxy for the size of the team involved in the development process.

The USPTO allows small entities (firms with less than 500 employees as well as public sector organizations) to renew their patents for lower fees.[9] Given that renewal decisions are influenced by maintenance costs, we use a dummy variable *SMALLENTITY* to take this into account.

3.5. Models

If markets (whether internal or external) can be viewed as a place where assets are priced based on their expected returns, it implies that patent quality metrics should be associated with renewals. As discussed above, patents that are renewed at year 12 can be viewed as not being followed thereafter (in the sense that their eventual death is never observed) and are thus right censored. Given this feature of patent renewal data, we employ, as our main econometric method, the Cox proportional hazards model using the patent's death as the hazard. The duration of the spell is indicated by the number of times the patent has been renewed: patents that have not been renewed at year four are declared dead after one period, those that are not renewed at year 8 are declared dead after two periods, those that are not renewed at year 12 are declared dead after three periods, and finally, those that are renewed at year 12 are right censored after four periods. Similar models have been used to assess patent survival rates (Maurseth, 2005; Van Zeebroeck and Van Pottelsberghe de la Potterie, 2011; Svensson, 2012). For robustness check, we further explore ordered probit regressions in which case right censoring is not taken into account. For further robustness check, we run three different logit regressions, one for each renewal decision year while using patent generality at that time as the explanatory variable.

By controlling for different patent quality indicators (including its generality), we can observe whether innovations are renewed at a higher rate by private sector organizations, which will contribute to testing H1. By interacting generality with the institutional form, we can observe whether there is a difference between how the private and public sectors renew their patents of more general purpose nature, which will contribute to testing H2. Finally, by comparing survival hazards for the most general purpose patents between universities and private sector organizations, we can test for H3.

4. Results

Tables 1 and 4 show descriptive statistics for our sample. One can note that close to 90% of patents are renewed at year 4. From these 789 initial patents, however, only 52% survive their entire legal life (i.e. are renewed at year 12). One should notice the possibility of multicollinearity due to the correlation between GENERALITY4,

[9] The USPTO requires that there must be no obligation to assign, grant, convey, or license any rights to the invention to any entity that would not, in turn, qualify for small entity status at the time that the Small Entity Status is claimed (US Patent & Trademark Office, 2001, §1.27(a)(2)(i)). Thus, SMEs or public organizations that are going to license their patents to firms that have more than 500 employees will not be able to claim for the Status. Therefore, the Status cannot be used as a proxy for firm size.

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Table 1
Descriptive statistics for the whole sample.

	Count	Mean	Std. dev.	Min	Max
RENEW4	789	0.9037	0.2952	0	1
RENEW8	789	0.7161	0.4512	0	1
RENEW12	789	0.5298	0.4994	0	1
GENERALITY4	789	0.2315	0.2669	0.0000	0.8571
GENERALITY8	789	0.3983	0.2855	0.0000	0.8980
GENERALITY12	789	0.4506	0.2771	0.0000	0.8994
UNI	789	0.1293	0.3357	0	1
SMALLENTITY	789	0.2218	0.4157	0	1
XEROX	789	0.3359	0.4726	0	1
CLAIMS	789	20.5830	14.2273	1	129
NBINV	789	3.0380	1.8927	0	13

Table 2
Descriptive statistics for firms.

	Count	Mean	Std. dev.	Min	Max
RENEW4	687	0.9112	0.2847	0.0000	1.0000
RENEW8	687	0.7263	0.4462	0.0000	1.0000
RENEW12	687	0.5400	0.4988	0.0000	1.0000
GENERALITY4	687	0.2303	0.2648	0.0000	0.8571
GENERALITY8	687	0.3858	0.2839	0.0000	0.8980
GENERALITY12	687	0.4373	0.2777	0.0000	0.8994
SMALLENTITY	687	0.1616	0.3683	0.0000	1.0000
XEROX	687	0.3857	0.4871	0.0000	1.0000
CLAIMS	687	20.7365	13.0747	1.0000	84.0000
NBINV	687	3.0640	1.9577	1.0000	13.0000

Table 3
Descriptive statistics for universities.

	Count	Mean	Std. dev.	Min	Max
RENEW4	102	0.8529	0.3559	0.0000	1.0000
RENEW8	102	0.6471	0.4802	0.0000	1.0000
RENEW12	102	0.4608	0.5009	0.0000	1.0000
GENERALITY4	102	0.2391	0.2822	0.0000	0.7811
GENERALITY8	102	0.4830	0.2836	0.0000	0.8651
GENERALITY12	102	0.5405	0.2568	0.0000	0.8580
SMALLENTITY	102	0.6275	0.4859	0.0000	1.0000
CLAIMS	102	19.5490	20.4187	1.0000	129.0000
NBINV	102	2.8627	1.3718	0.0000	8.0000

GENERALITY8 and GENERALITY12. Therefore, we will use GENERALITY12 as the main effect in our models. Fig. 1 shows a histogram of GENERALITY12 for the whole sample. As we can see, many patents are of special purpose nature as they either receive their citations from the same technological classes or are not cited at all. Tables 2 and 3 provide summary statistics by splitting the sample into firms and universities respectively. Overall, patents owned by firms are more likely to live their full life. Also, patents owned by universities are of more general nature ($t = -3.54$, $p < 0.001$ for a t-test comparing GENERALITY12 between universities and private sector organizations). It should also be noticed that generality tends to be positively correlated with UNI as time increases (GENERALITY4 is not significantly different between university-owned and firm patents), suggesting that public sector patents are of more general purpose nature and stay that way for a longer period. Similarly, one can observe positive correlation with long-term generality of university patents. No statistical difference is found between universities and firms in terms of the number of claims or inventors per patent.

Table 5 shows the marginal effects of our main hierarchical Cox proportional hazards regressions. We report robust standard errors clustered by assignee. As our base specification, Model 1 includes the set of control variables including year dummies. As we can see in Model 2, an increase in one unit of generality (note that generality is bounded between 0 and 1) decreases the likelihood of non-renewal on average by 16.74%. This finding is consistent with H1: more general purpose inventions are more profitable for the owner. Model 3 shows that ownership by universities also increases the risk of death. Model 4 adds both generality and university to the model: the effects of both variables remains significant and of the same magnitude. This finding suggests that the relationship between university and renewal might not be mediated by generality: the marginal effect of UNI is essentially the same and does not change in significance when GENERALITY12 is added. This finding provides

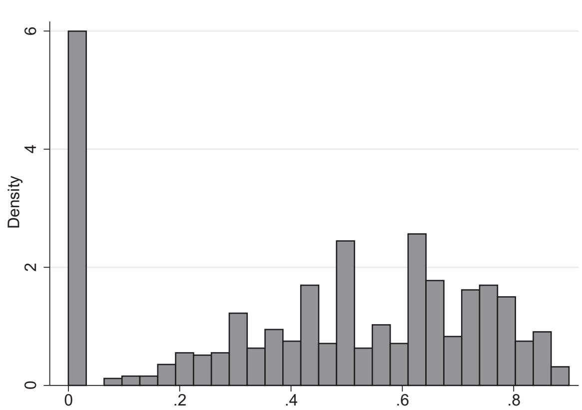

Fig. 1. Histogram of the generality of the 789 patents after 12years.

support for our second hypothesis: controlling for generality and other patent quality measures, university-owned patents are less likely to survive. Model 5, our main model,[10] adds interaction effects between GENERALITY12 and UNI. As we can see, the sign of the interaction effect indicate a significant association with decreasing death. Furthermore, marginal effects for hazard rates of university patents increases suggesting that most of the renewal comes from general purpose patents. These results support our third hypothesis: the generality of university patents increases survival rates relative to private sector organizations.

Fig. 3 shows average marginal effects of UNI at different values of generality. As we can see, universities will always renew their patents at a lower rate than private sector organizations, although the effect is not significant for patents with a GENERALITY12 of 0.6 or more. Although the estimated marginal effect for the most general purpose invention (i.e. when GENERALITY12 $= 1.0$), our sample does not contain any instance of such highly general patent. These results give partial support for our fourth hypothesis: although we cannot rule out the possibility that universities are able to profit from very highly basic inventions more than private sector organizations, the general picture seems to suggest that the expected private returns from the most general purpose patents is at most at par with those of the private sector firms.

We check the robustness of the above findings by first excluding and then controlling for Xerox, the largest patent holder in our sample. Results are shown in Tables 6 and 7 and are very similar to those in Table 5. We have further tested the robustness of our findings by resorting to ordered probit regressions. We also control for a patent's originality[11] and find similar results, indicating that the relationship

[10] Fig. 2 plots the smoothed hazard function at the means of the covariates for this model. As we can see, the hazard of patent death increases as we go to the next renewal stage.
[11] Originality is computed using the same formulation as in Eq. (1), except that it is based on backward citations. Originality can be seen as an indication of how much a patent is sourced from different technological fields. It turns out that this measure is highly correlated with Generality (Trajtenberg et al., 1997).

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Table 4
Correlation matrix.

		1	2	3	4	5	6	7	8	9	10	11
RENEW4	1	–										
RENEW8	2	0.5185	–									
RENEW12	3	0.3465	0.6683	–								
GENERALITY4	4	0.0470	0.1398	0.1549	–							
GENERALITY8	5	0.0607	0.1009	0.0846	0.6281	–						
GENERALITY12	6	0.0385	0.1058	0.0918	0.5192	0.8617	–					
UNI	7	−0.0663	−0.0590	−0.0533	0.0110	0.1143	0.1251	–				
SMALLENTITY	8	0.1743	0.0520	0.0323	0.0363	0.1014	0.1045	0.3762	–			
XEROX	9	0.2322	0.1323	0.0893	−0.0036	−0.1051	−0.1559	−0.2740	−0.3797	–		
CLAIMS	10	0.0777	0.0948	0.1090	0.0783	0.0148	0.0065	−0.0280	−0.0700	0.2413	–	
NBINV	11	0.0384	0.1568	0.1612	0.0673	0.0060	−0.0014	−0.0357	−0.1462	0.2212	0.1800	–

Table 5
Marginal effects for Cox proportional hazards models with university interactions, controlling for NANOBIO.

	(1)	(2)	(3)	(4)	(5)
SMALLENTITY	−0.1435**	−0.1192**	−0.1876***	−0.1596***	−0.1737***
	(0.0566)	(0.0523)	(0.0639)	(0.0572)	(0.0616)
CLAIMS	−0.0043**	−0.0038**	−0.0041*	−0.0036**	−0.0039**
	(0.0021)	(0.0019)	(0.0021)	(0.0018)	(0.0018)
NBINV	−0.0505****	−0.0436***	−0.0515****	−0.0439***	−0.0467***
	(0.0151)	(0.0135)	(0.0154)	(0.0135)	(0.0146)
NANOBIO	0.0663	0.0603	0.0410	0.0351	0.0385
	(0.0574)	(0.0514)	(0.0574)	(0.0506)	(0.0533)
GENERALITY12		−0.1674***		−0.1857***	−0.2118****
		(0.0593)		(0.0607)	(0.0638)
UNI = 1			0.1914*	0.1940**	0.2767***
			(0.1007)	(0.0906)	(0.1024)
UNI = 1×GENERALITY12					−0.7177**
					(0.2999)
Year dummies	Yes	Yes	Yes	Yes	Yes
Observations	789	789	789	789	789
df	11	12	12	13	14
# Clusters	234	234	234	234	234
p-Value	0.0000	0.0000	0.0000	0.0000	0.0000
χ^2	58.9889	64.3923	66.7980	71.2905	81.7333
Log-likelihood	−2389.8691	−2387.0410	−2387.1646	−2383.5609	−2382.0404

Standard errors are in parentheses.
* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.
**** $p < 0.001$.

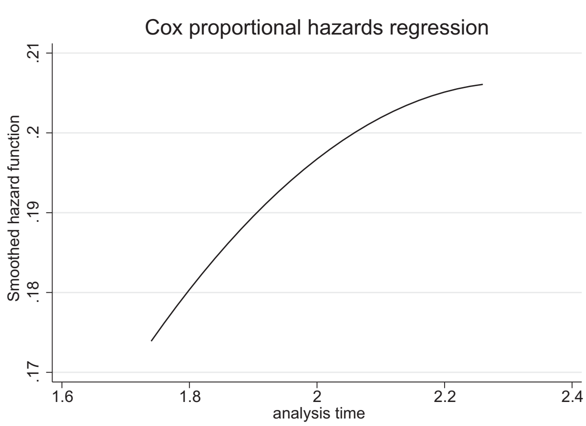

Fig. 2. Baseline hazard function for the main model. Analysis time is the stage at which renewal decision is made. Analysis time=1 indicates renewal decision at year 4.

between renewal and generality is robust to taking into account a patent's technological potential.[12] For brevity, these results are not tabulated but are available from the authors upon request.

We have also run logit regressions for each of the three years where a renewal decision has to be made. For these sets of regressions, the patent's generality at the year where the renewal decision has to be made is modeled as an explanatory variable. For the 8th year, only patents that have been renewed at the 4th year are taken into account. Similarly, for the 12th year, only patents that have been

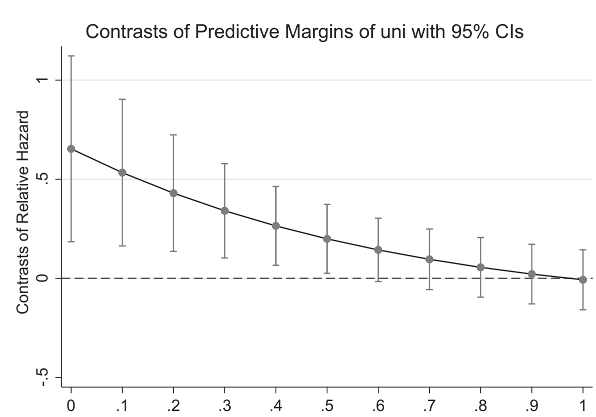

Fig. 3. Average marginal effect of UNI at representative values of GENERALITY12 for models with university interactions, controlling for NANOBIO.

[12] Subsequently, we have treated patent generality as an endogenous variable and used originality as an instrument in a 2SLS framework. Postestimation test of endogeneity fails to reject the null hypothesis that patent generality is exogenous.

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Table 6
Marginal effects for Cox proportional hazards models with university interactions, controlling for NANOBIO and excluding Xerox patents from sample.

	(1)	(2)	(3)	(4)	(5)
SMALLENTITY	−0.1922***	−0.1627**	−0.2349***	−0.2014***	−0.2181***
	(0.0701)	(0.0634)	(0.0790)	(0.0700)	(0.0763)
CLAIMS	−0.0012	−0.0008	−0.0014	−0.0009	−0.0012
	(0.0027)	(0.0023)	(0.0026)	(0.0022)	(0.0023)
NBINV	−0.0504**	−0.0396**	−0.0525**	−0.0405**	−0.0442**
	(0.0230)	(0.0201)	(0.0235)	(0.0201)	(0.0220)
NANOBIO	−0.0043	−0.0139	−0.0266	−0.0359	−0.0340
	(0.0664)	(0.0591)	(0.0663)	(0.0577)	(0.0621)
GENERALITY12		−0.2237**		−0.2464**	−0.2765**
		(0.1043)		(0.1050)	(0.1099)
UNI = 1			0.1979*	0.1994**	0.2592**
			(0.1082)	(0.0980)	(0.1121)
UNI = 1 × GENERALITY12					−0.6768**
					(0.3541)
Year dummies	Yes	Yes	Yes	Yes	Yes
Observations	524	524	524	524	524
df	11	12	12	13	14
# Clusters	234	234	234	234	234
p-Value	0.0035	0.0007	0.0006	0.0002	0.0000
χ^2	27.8109	33.7413	34.4677	39.2200	55.0427
Log-likelihood	−1586.1101	−1583.8623	−1583.9711	−1581.1149	−1580.0855

Standard errors are in parentheses.
* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.

renewed at the 8th year are taken into account. Results (in Table 8) show that although university-owned patents are less likely to be renewed in the fourth year, they are relatively more likely to be renewed at the 12th than firm-owned patents as their generality increases. This further provides support for H3.

We further test the robustness of our findings with regard to the inclusion of the number of forward citations to our models. This can help test whether the results are driven by cash constrained universities that only renew patents that have greater impact. This is not a straightforward check since our measure of generality is in fact a transformation performed on a patent's forward citations. Including both the number of forward citations and generality can therefore lead to multicollinearity problems. For this purpose, we have computed a normalized measure of generality based on the number of classes in which a patent's forward citations fall. Following Gaur et al. (2013), normalized generality is given by $\hat{G} = \frac{G-\frac{1}{m}}{1-\frac{1}{m}}$ where m and G are defined as in Eq. (1). Intuitively, this formulation of

Table 7
Marginal effects for Cox proportional hazards models with university interactions, controlling for XEROX.

	(1)	(2)	(3)	(4)	(5)
SMALLENTITY	−0.1607***	−0.1354***	−0.2019****	−0.1727****	−0.1850****
	(0.0492)	(0.0442)	(0.0578)	(0.0510)	(0.0546)
CLAIMS	−0.0029	−0.0024	−0.0029	−0.0024	−0.0026
	(0.0019)	(0.0017)	(0.0019)	(0.0016)	(0.0017)
NBINV	−0.0410***	−0.0334***	−0.0434***	−0.0351***	−0.0373***
	(0.0135)	(0.0114)	(0.0143)	(0.0119)	(0.0129)
XEROX	−0.1419***	−0.1385***	−0.1264***	−0.1234***	−0.1280***
	(0.0474)	(0.0456)	(0.0440)	(0.0411)	(0.0430)
GENERALITY12		−0.1799***		−0.1962***	−0.2198****
		(0.0590)		(0.0610)	(0.0627)
UNI = 1			0.1611*	0.1601*	0.2276**
			(0.0939)	(0.0823)	(0.0929)
UNI = 1 × GENERALITY12					−0.6114**
					(0.2698)
Year dummies	Yes	Yes	Yes	Yes	Yes
Observations	789	789	789	789	789
df	11	12	12	13	14
# Clusters	234	234	234	234	234
p-Value	0.0000	0.0000	0.0000	0.0000	0.0000
χ^2	79.5187	89.3380	90.4924	104.6418	133.0867
Log-likelihood	−2386.7402	−2382.8818	−2384.4408	−2379.8845	−2378.5566

Standard errors are in parentheses.
* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.
**** $p < 0.001$.

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Table 8
Marginal effects for logit regressions associating the likelihood of patent renewal with its generality at the renewal year.

	RENEW4		RENEW8		RENEW12	
	(1)	(2)	(3)	(4)	(5)	(6)
SMALLENTITY†			−0.0309	−0.0310	0.0283	0.0322
			(0.0432)	(0.0432)	(0.0510)	(0.0510)
CLAIMS	0.0019	0.0019	0.0012	0.0012	0.0021*	0.0021*
	(0.0014)	(0.0014)	(0.0018)	(0.0018)	(0.0013)	(0.0012)
NBINV	0.0092	0.0097	0.0415****	0.0414****	0.0161**	0.0166**
	(0.0079)	(0.0079)	(0.0105)	(0.0105)	(0.0076)	(0.0076)
NANOBIO	−0.1033***	−0.1046***	0.0875**	0.0880**	−0.0264	−0.0238
	(0.0319)	(0.0320)	(0.0359)	(0.0360)	(0.0540)	(0.0538)
UNI = 1	−0.2008***	−0.1959***	−0.0743	−0.0790	−0.0480	−0.1101
	(0.0724)	(0.0715)	(0.0508)	(0.0508)	(0.0886)	(0.0842)
GENERALITY4	0.0479	0.0496				
	(0.0554)	(0.0580)				
UNI = 1×GENERALITY4		−0.1080				
		(0.2226)				
GENERALITY8			0.1223**	0.1223**		
			(0.0480)	(0.0488)		
UNI = 1×GENERALITY8				0.0857		
				(0.1790)		
GENERALITY12					0.1025*	0.1177*
					(0.0610)	(0.0659)
UNI = 1×GENERALITY12						0.4959*
						(0.2281)
Constant	0.5121	0.4818	−0.2491	−0.2328	0.5118	0.5814
	(0.5875)	(0.5914)	(0.6321)	(0.6364)	(0.4318)	(0.4469)
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes
Observations	614	614	713	713	565	565
df	12	13	13	14	13	14
# Clusters	154	154	216	216	173	173
p-Value	0.0001	0.0002	0.0001	0.0001	0.0012	0.0015
χ^2	39.0220	39.0183	42.0414	43.4668	33.9826	34.9419
Log-likelihood	−199.7897	−199.5869	−343.9098	−343.8571	−305.9438	−304.2778

Standard errors in parentheses.
* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.
**** $p < 0.001$.
† Small Entity patents were dropped in the logit regression for the renewal regression at year 4 because SMALLENTITY = 1 perfectly predicts renewal at that year. Notice that (university and private sector) patents that do not have the small entity status are not dropped from the regression.

generality abstracts from the number of forward citations as it only measures to what degree forward citations are evenly spread across different technological classes. As we can see in Table 9, our main results are robust to the inclusion of the number of forward citations as a control variable. As we can see, whether we employ the normalized measure of generality (Model 2) or not (Model 1), the results are the same (Figs. 4 and 5).

To further test the fourth hypothesis, we rerun our analysis of interaction effects between UNI and GENERALITY12 by splitting the sample of university patents based on whether they had a fully developed technology transfer office (TTO) in 1991 or not. No significant difference is observed when comparing observable characteristics of university-owned patents that have a TTO or not: *t*-tests show that both sub-samples of patents have the same level of generality, number of claims, and inventors. The results of Cox proportional hazards models are shown in Model 1 from Table 10 where firm-owned patents – the base category – are compared with university owned patents with (WITH_TTO) or without (WITHOUT_TTO) a TTO. As we can, see from the marginal effects of university ownership of a patent, having a fully developed TTO or not does not make any difference: both patents owned by universities with and without a TTO are less likely to survive when compared with firm-owned patents. However, as we can see from the interaction effects with GENERALITY, universities without a TTO are not significantly more able to profit from general purpose inventions than firms. In other words, most of the difference between universities and firms in terms of appropriation of benefits from general purpose inventions can be associated with patents owned by universities that have a fully developed TTO. If one views a TTO as a complementary asset for universities, this result is evidence that a lack of complementary assets can hinder the ability of universities to appropriate returns from their general purpose inventions.

We have also run robustness checks regarding H4 by exploiting a feature of the small entity status related to the fact that patent assignees cannot apply for small entity status if their patents are destined for use by a large firm. We exploit this fact to split university-owned patents based on whether they have the small entity status (UNI_SMALLENTITY) or not (UNI_NO_SMALLENTITY) and comparing them with firm-owned patents that are again the base category. Again, patent characteristics do not differ significantly between university-owned patents that have the small entity status and university owned patents that do not have the small entity status. Regression results are shown in Model 2 from Table 10. As we can see, most of the difference between firms and universities in terms of benefiting from general purpose inventions comes from university-owned patents that do not have the small entity status. This result is evidence that a lack of ownership in downstream assets can hinder the ability of an organization to profit from general purpose inventions. Indeed, university patents that do not have the small entity status are likely to be licensed-out to large firms, in which case the

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Table 9
Marginal effects for Cox proportional hazards models taking the number of forward citations into account.

	(1)	(2)
SMALLENTITY	−0.1668***	−0.1611***
	(0.0595)	(0.0582)
CLAIMS	−0.0033**	−0.0032**
	(0.0016)	(0.0016)
NBINV	−0.0429***	−0.0415***
	(0.0136)	(0.0134)
NANOBIO	0.0336	0.0315
	(0.0496)	(0.0486)
NBFORWCIT12	−0.0042**	−0.0045***
	(0.0018)	(0.0016)
GENERALITY12	−0.1247*	
	(0.0702)	
UNI = 1	0.2655***	0.2387**
	(0.0966)	(0.0945)
UNI = 1×GENERALITY12	−0.6248*	
	(0.2785)	
NORMBASICNESS12		−0.0913*
		(0.0474)
UNI = 1×NORMBASICNESS12		−0.6248*
		(0.2785)
Year dummies	Yes	Yes
Observations	789	789
df	15	15
# Clusters	234	234
p-Value	0.0000	0.0000
χ^2	74.6259	72.6731
Log-likelihood	−2375.8982	−2376.3758

Standard errors are in parentheses.
* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.

ownership of downstream assets by the latter boosts the commercial potential of the general purpose patent, leading to greater expected profits accruing to the upstream supplier (the university).[13]

5. Discussion and conclusion

In this paper, we have explored the possibility of institutional form moderating the relationship between an invention's generality and its expected returns. For this purpose, we have employed a sample of Canadian nanobiotechnology patents for which we have built models to explain renewals over their lifetime. The analysis of patent renewal decisions over a period of 12 years seems to provide partial support for our hypotheses. Our results concord with previous findings regarding the greater expected returns from general purpose patents as well as smaller expected returns from patents owned by universities (Maurseth, 2005; Sakakibara, 2010). We find that the tendency for universities to renew their patents is positively moderated by the patent's generality. These findings are in line with a perspective that small upstream technology specialists are better off developing and commercializing general purpose technologies (Gambardella and McGahan, 2010).

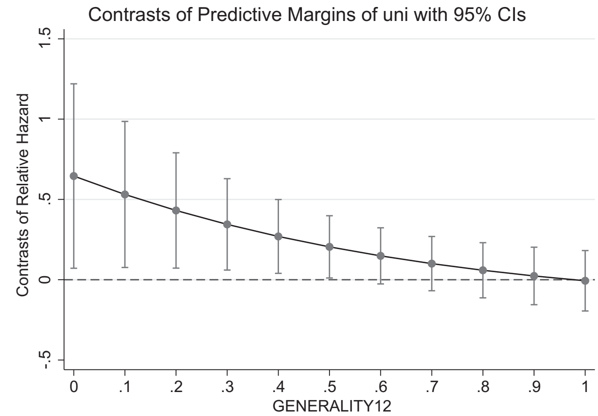

Fig. 4. Average marginal effect of UNI at representative values of GENERALITY12 for models with university interactions, controlling for NANOBIO and excluding Xerox patents from sample.

Although we cannot rule out that universities benefit from general purpose technologies as much as private sector organizations do, we observe that universities trail behind for most levels of generality and never actually surpass private sector organizations. Thus, empirical evidence does not seem to support the idea that savings in disintegration costs associated with general purpose inventions can overtake the various sources of competitive disadvantage that afflict universities.

The academic enterprise paradigm stipulates that the nature of universities is a changing one, with increasing proximity with the industry and greater self-reliance in terms of revenue streaming. The fact that public research organizations have been historically linked with the generation of general purpose inventions could mean that the power of markets for technology can be unleashed to fill some of the gaps left by decreasing public funding of research. However, capabilities in terms of lack of control over complementary assets, institutional distance with private sector organizations and quasi-exclusive reliance on licensing as a mean to profit from inventions could pose serious challenges to the feasibility of such visions.

We will close with some comments about the limitations of our study. First, one should note that earlier forfeiting of general purpose inventions does not automatically rule out efficiency by private sector organizations compared to public sector organizations. It should also be noted that longevity in generality could also mean slower adoption and longer required period to cash in returns. One needs

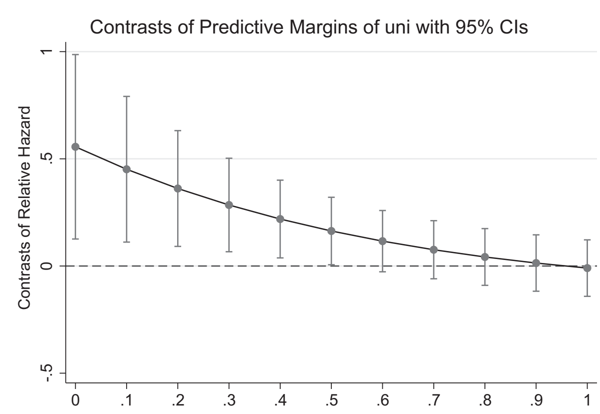

Fig. 5. Average marginal effect of UNI at representative values of GENERALITY12 for models with university interactions, controlling for XEROX.

[13] Subsequently, we split the sample of firm-owned patents depending on whether the assignee owns an above average number of patents, and compare them with university-owned patents. Firms that have applied for the small entity status on at least one of their patents own significantly more patents than firms that have never applied for the small entity status. We find that most of the difference between university-owned patents and firm-owned patents comes from firms that own more than average number of patents. This result is also consistent with the idea that smaller firms, which should not own downstream assets of the same magnitude than large firms, also benefit from savings in disintegration costs. For sake of brevity, we are not tabulating these results.

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Table 10
Marginal effects for Cox proportional hazards models predicting the likelihood of patent survival.

	(1)	(2)
SMALLENTITY	−0.1745***	−0.1562**
	(0.0624)	(0.0689)
CLAIMS	−0.0040**	−0.0040**
	(0.0018)	(0.0019)
NBINV	−0.0461***	−0.0463***
	(0.0143)	(0.0145)
NANOBIO	0.0378	0.0412
	(0.0541)	(0.0538)
GENERALITY12	−0.2098***	−0.2336****
	(0.0639)	(0.0703)
WITH_TTO	0.2615**	
	(0.1318)	
WITOUT_TTO	0.2943***	
	(0.1086)	
WITH_TTO×GENERALITY12	−0.9233**	
	(0.4291)	
WITOUT_TTO×GENERALITY12	−0.5186	
	(0.3433)	
UNI_SMALLENTITY		0.1910*
		(0.1110)
UNI_NO_SMALLENTITY		0.4373**
		(0.1771)
UNI_SMALLENTITY×GENERALITY12		−0.4336
		(0.2976)
UNI_NO_SMALLENTITY×GENERALITY12		−1.4731*
		(0.8061)
Year dummies	Yes	Yes
Observations	789	789
df	16	16
# Clusters	234	234
p-Value	0.0000	0.0000
χ^2	92.1056	94.4407
Log-likelihood	−2381.6360	−2381.3930

Standard errors are in parentheses.
* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.
**** $p < 0.001$.

to verify whether the production of general purpose inventions has a more expensive cost function in the private sector before concluding on the efficiency of competing with universities in the markets for technology. Given the historical proximity that universities have with developments in basic sciences, this is not a straightforward assumption to make. One should note that Coupe (2003) finds that the elasticity of financing to patent production is similar between private and public sector organizations.

Furthermore, it should be noted that there could be endogeneity between generality and renewal. Firms that renew patents might commit resources to their development, which might contribute to their improvement and which will have positive feedback on their subsequent spread over technological fields. Lacking instrumental variables, we are unable to say how such effects will impact our estimates. In fact, our results mostly hold for ex post measures of diffusion measured by the spread of forward citations as it turns out that ex ante measures based on the spread of backward citations are only weakly associated with renewals. Moreover, our measure of generality being a continuous variable, the interpretation of results might not be readily transferable for a dichotomous representation of generality normally associated with the notion of general purpose technologies.

One limitation to this study is the lack of firm-level data, which leads to us not being able to directly test whether small firms are able to tap into disintegration costs economies. Although exploiting particular aspects of the Small Entity Status allows us to provide indirect support, we cannot rule out that institutional differences between the private sector and universities does not have an impact on our results. Future studies can benefit from matching patent data with firm-level data to test such propositions.

Finally, one should notice that many intertwined factors can be associated with heterogeneous institutional renewal decisions. Public sector organizations can lack the ability in coordinating and bargaining complex contracts, but also be in a position of weak bargaining due to lack of complementary assets. The first factor can be overcome through adoption of best practices in terms of technology transfer, but the second factor cannot, by definition, be palliated without dismantling public institutions altogether. Our study does not disentangle these different factors. By not controlling for the distinctive effect of these two factors, we cannot comment on how technology transfer best practices can entirely bring institutional capabilities at a plain level field. This means that differences in patent renewal decision patterns between the private and the public sector might be converging in the long run, especially if a greater share of the difference happens to be imputed to factors that can be improved within the institutional constraints imposed upon public sector organizations. Trends in terms of ratios of university spinoffs per invention disclosures might also evolve over time and lead to different renewal rates by universities.

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Appendix A. Data collection methodology

The sample of USPTO granted Canadian nanotechnology patents were obtained by performing a lexical extraction on patents containing nanotechnology related keywords. Following influential bibliographic studies (Alencar et al., 2007; Fitzgibbons and McNiven, 2006; Noyons et al., 2003; Mogoutov and Kahane, 2007; Porter et al., 2008; Zitt and Bassecoulard, 2006), we have retained keywords that are used in more than one of these studies. Canadian nanotechnology patents are defined as granted patents that contain one of these keywords in all their fields and that have been assigned to Canadian organizations or for which one of the inventors resides in Canada. The sample is also expanded by patents classified under USPTO class 977 which has been reserved for nanotechnology.[14] Table A.11 shows the core keywords for which at least one Canadian patent was extracted from the USPTO database. For each patent, data about the title, abstract, grant date, number of claims, references, backward and forward citations, as well as the name, city and country of inventors and firms are extracted. After cleaning for duplicates and missing data, our sample contains 6288 unique Canadian nanotechnology patents obtained from 1990 to 2009. This sample is used to build a co-citation network. From this network's main component, three distinct fields (nanobiotechnology, printing technologies, and optical technologies) emerge. A K-NN classifier is trained on that main component to learn how to classify patents into these three fields based on the patents' tokenized titles and abstracts. That classifier is then used to classify the patents that are not part of the co-citation network's main component. Because generality is measured for up to 12 years after the patent has been granted, we only consider patents obtained from 1990 to 1997 in the current study.

[14] At the time of data extraction, the USPTO assigned 156 Canadian patents to class 977, 12 of which were missed by our lexical query. We thus believe that our sample is a good representation of Canadian nanotechnology patents.

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Table A.11
Keywords used in lexical patent extraction.

Term	Patents	Term	Patents	Term	Patents
Atom* force microscop*	88	Molecular beam epitaxy	77	Polymer protein	38
Biosensor	231	Molecular engineering	44	Polymer rna	3
Drug carrier	182	Molecular motor	5	Polymer virus	2
Drug delivery	972	Molecular switch	22	Quantum	1077
Gene delivery	239	Molecular template	3	Scanning prob*	30
Gene therapy	906	Nano* (excluding nano2, nano3, nano4, nano5, nano*aryote*, nanoalga*, nanobacteri*, nanofauna*, nanoflagel*, nanoheterotroph*, nanoliter*, nanomeli*, nanophtalm*, nanophyto*, nanoprotist*, nanosecond*, plankton*)	3188	Scanning probe microscop*	16
Immobilized dna	22	Nems	5	Self assem*	219
Immobilized polynucleotide	1	Photonic*	868	Single electron*	75
Immobilized primer	1	Polymer composite*	261	Supramolecular chemistry	12
Immobilized template	2	Polymer dna	9	Transmission electron microscopy	198
Mesoporous material*	20	Polymer enzyme	15	Tunnel* microscop*	2
Molecular beacon	13	Polymer polynucleotide	3		

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