Universities as Innovators: The Effects of Academic Incubators on Patent Quality

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Abstract: Despite a wealth of research on university incubators, science parks, and other attempts at commercialization, there is little consensus on the effectiveness of university-sponsored commercial innovation. We analyze the impact of incubators and other types of facilitators on the quality of innovations produced by US research-intensive academic institutions from 1969 to 2012. Using forward patent citations to measure the quality of innovation we show that establishing a university-affiliated incubator is followed by a reduction in innovation on campus, controlling for patent-, university-, and time-specific characteristics. The results hold when we control for the endogeneity of the decision to establish an incubator using the presence of incubators at peer institutions as an instrument. The results suggest that university incubators compete for resources with technology transfer offices and other campus programs and activities, such that the useful and commercializable outputs they generate can be partially offset by reductions in innovation elsewhere on campus.

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1. Introduction

Universities are increasingly tasked with fostering entrepreneurship and innovation, encouraged to generate revenues from research produced on campus and contribute to (local) economic growth (Etzkowitz, 1998, 2002; Etzkowitz et al., 2000; Goldstein and Renault, 2004). This view of the entrepreneurial university reflects two recent trends. First, universities are increasingly patenting research with commercial potential and subsequently seeking to increase their licensing revenues (Bulut and Moschini, 2009; Henderson et al., 1998). At the same time, universities are creating incubator facilities to assist faculty members, university graduates, community members, or other parties to start new firms that not only contribute to local economic growth, but also generate income for the university which often holds equity positions in the incubator's tenant firms.

Establishing university incubators and increasing university patenting have similar underlying motivations: both are mainly motivated by reductions in public funding for academia and increasing pressures for public accountability. Moreover, the resources and capabilities used to support start-ups and to generate patented inventions are largely shared: maintaining these two activities simultaneously involves leveraging the same academic knowledge and talent, devoting dedicated personnel for patent-issuing procedures and auxiliary services to start-ups, as well as directing significant investments for research equipment that can be used not only by university faculty and staff but also by incubator tenants. By extension, the overlap of goals and resources between university patenting and incubators suggests that decisions to increase university revenue and contribute to innovation and local economic growth through the twin channels of patenting and incubator activities are made jointly. This observation calls for reflection upon the basic, yet unexplored, question of how each channel affects the other. In this paper we begin addressing that question by examining empirically whether the quality of university patents is influenced by the creation of incubator facilities across research-intensive US universities across time.

Theoretically, the creation of incubation facilities can improve the quality of university patents by facilitating knowledge flows between academic inventors and market participants, knowledge that can not only help university patents articulate the commercial value of their inventions but also help generate ideas to university inventors that lead to valuable patents. Moreover, assuming that industry–academia collaboration often yields superior outcomes, incubators can lead to higher-quality patents if incubator tenants collaborate with university inventors. On the other hand, the presence of an incubator can reduce the quality of university patents if auxiliary incubator services and patenting activities compete for the same scarce university resources such as funds and dedicated personnel. Similarly, the average quality of university patents may fall once an incubator is in place if the university's overall focus and associated investments and resources shifts towards start-ups over high-quality patenting. Our research aims to see which effect outweighs the other.

We must keep in mind, however, that the decision to establish an incubator can be endogenous; if incubators are followed by increases in patent quality, this could indicate that universities with good projects in the pipeline, and the prospect of high-quality patents down the road, choose to establish an incubator, even though there is no direct effect of incubators on patent quality. Likewise, a decline in patent quality following the establishment of an incubator could indicate that the university expects patent quality to decrease, and establishes an incubator as an alternative mechanisms for generating revenue and fulfilling its entrepreneurial mission.

Theorizing about the connection between incubators and patent quality and empirically testing that connection have not, as far as we are aware, been addressed in previous work. We also add to the literature on the quality of university patenting which, in addition to insightful, mainly descriptive historical accounts (Henderson et al., 1998), has focused primarily on the effects of regulatory interventions such as the Bayh-Dole Act and the impact of university experience and other university-specific features (e.g. Mowery et al., 2002; Mowery and Ziedonis, 2002; Owen-Smith and Powell, 2003; Sampat et al., 2003).

Our empirical work follows convention in approximating patent value with the number of times a given patent is cited by subsequent patents (forward citations) (e.g. Harhoff et al., 1999; Lerner, 1994). We run a series of regressions that compare patent quality before and after an incubator is established, controlling for patent-, university-, and time-specific characteristics that may affect patent quality. To mitigate endogeneity, we also run instrumental-variables regressions; our identification strategy builds on the insight that universities compete with each other and tend to imitate their peer institutions, particularly those that are geographically close (Rey, 2001). Hence we use the presence of incubators at similar, nearby (and potentially competitor) universities as an instrument for the focal university's decision to establish an incubator.

To build our dataset, we collect information on all 55,919 patents granted from 1969 to 2012 to US-based universities that were members of the Association of American Universities as of the end of 2012. These universities are research-intensive, they patent extensively, and those that have established incubators have done so in different years, which allows enough time variation in our sample.

Our results suggest that, in terms of generating useful innovation, the value-added of university incubators may have been overstated: we find a strong negative association between the establishment of an incubator and the quality of patents produced subsequently by that university. This relationship holds across a variety of empirical specifications, using different control variables, adding indicators for university and year, and controlling for endogeneity using the instrument described above. The results support the idea that incubators and university patenting rely on similar resources, so that resource scarcity may be driving the negative relationship between incubators and subsequent patent quality.

This finding has important policy implications. University administrators, technology transfer office officials, and other stakeholders generally show a keen interest on the effects of incubators and university patenting (Carlson, 2000; Guy, 2013). This interest is understandable because patenting and incubation are two prime means for universities to fulfil their new roles of generating economic growth and securing income. If these two means compete for similar scarce resources, then establishing an incubator may, on balance, reduce the quality of the innovative outputs produced by the university. Our work suggests that these innovation channels should be treated jointly, as alternative, and potentially competing, means of fostering innovation and economic growth. In sum, adopting a new lens via which incubation and patenting are analyzed jointly can help decision makers in determining the most effective means for academic institutions to meet the expectations that arise from their new roles.

We organize the rest of the paper as follows: In the next section we review the relevant literature and develop our theoretical expectations on the effects of incubators on patent quality. In Section 3 we describe our econometric model and estimation procedures, and in Section 4 we review the data we use. In Section 5 we present the estimation results. Finally, we conclude in Section 6.

2. The relationship between university patenting and university incubators

Universities have long been central to the innovative process through generating, codifying, and communicating basic knowledge. Since the middle of the 20th century, universities have also played an increasingly important role in developing and using applied knowledge, particularly in the scientific and technical fields (Henderson et al., 1998). Universities often serve as "anchors" in the emergence of technology clusters (Stanford University, in the heart of Silicon Valley, being the best-known example) (Swann and Prevezer, 1996). Universities train scientists and engineers, partner with established and emerging technology firms, and develop their own in-house technologies. The desire to increase universities' applied research outputs and give them a stronger role in the innovative process has led US policymakers to describe local economic development as a "fourth mission" of the public research university (along with research, teaching, and service) (Etzkowitz et al., 2000; Youtie and Shapira, 2008).

Universities also attempt to foster innovation and economic development directly by establishing business incubators. Business incubators ("incubators" for short) are organizations that help aspiring entrepreneurs translate ideas into profitable ventures. Incubators typically provide office space, consulting services, assistance in finding suppliers and distributors, access to venture capitalists and business angels, and sometimes direct financial support (Aernoudt, 2004; Finer and Holberton, 2002; Rothaermel and Thursby, 2005a). Incubators are operated by a variety of private and public actors including government agencies and NGOs, but more than half of US incubators are affiliated with higher-educational institutions (Powell, 2013). University incubators (also called university technology business incubators or UTBIs) provide additional services to their tenant firms such as access to university labs and computing facilities, student workers, and faculty consultants (Mian, 1996). Their on-campus or near-campus location and close relationships with university personnel also make it easier for university faculty and students to establish their own ventures and become incubator tenants.[1] By 2012 all but ten of the

[1] In emerging economies, incubators provide even more foundational support, helping firms establish basic supplier and customer relationships, write and enforce contracts, and so on – helping to establish market institutions rather than developing specific business capabilities (Dutt et al., 2013).

US members of the Association of American Universities (AAU) had established a campus incubator.[2]

Another approach for encouraging university innovation is to assist faculty, staff, and students in patenting innovations developed within the university. The prospect of a patent provides an important financial incentive for university personnel to devote time and effort to potentially valuable commercial technologies (Lach and Schankerman, 2008; Owen-Smith and Powell, 2001; Thursby et al., 2001)[3]. To facilitate patenting, many universities have established technology transfer offices to ease the administrative burden of the patent application process and to manage the use of patents that are successfully obtained. Often the university itself will be the patent holder, sharing licensing income with individual scientists; in other cases, faculty members retain patent rights. The Association of University Technology Managers (AUTM), which represents technology transfer offices, reports that universities earned $2.6 billion in license fees in 2012. Of course, not all innovations are patentable, and not all patentable ideas are innovative. Nonetheless, patents serve as a useful proxy for (quality of) innovation (Acs et al., 2002; Igami, 2013), so we can draw inferences about the strength of a university's innovative programs by examining its portfolio of university-owned patents.

There is a large literature on the use of patents and patent citations as proxies for innovation. Importantly, "innovation," as famously characterized by Schumpeter (1934), includes not only the introduction of new products and services, but refers also to the establishment of new production methods, new sources of supply, new consumer markets, and new methods of organization. Nonetheless the innovation literature has tended to focus more narrowly on technological innova-

[2] Journalist Nicholas Thompson (2013) wrote of Stanford: "Students can still study Chaucer, and there are still lovely palm trees. But the center of gravity at the university appears to have shifted. The school now looks like a giant tech incubator with a football team."

[3] Others have reached opposite conclusions about the incentives of academics to commercialize their research (Colyvas et al., 2002; Markman et al., 2004)

tion and to rely on patents as reasonable indicators of innovation (Acs et al., 2002; Igami, 2013). We follow that convention here.

Like most of the recent literature on technological innovation, we focus on patent quality, not quantity. Citations of patents by future patent applications ("forward patent citations") are commonly used to measure quality (Harhoff et al., 1999; Igami, 2013). The intuition behind the forward-citations measure is that higher citation levels imply superior scientific significance or applicability. Indeed, studies have consistently shown that forward citations correlate strongly with realized market value for a particular patent (e.g. Harhoff et al., 1999; Lerner, 1994). [4] Nevertheless, more recent patents tend to receive fewer citations largely due to the effective time needed before they become visible. Most patents receive their citations in the first few years after issue. In the same vein, the secular increase in the annual number of patents over time implies that very early patents may also tend to have fewer citations than more recent patents. Other things equal, then, earlier patents should have fewer forward citations than later patents simply because there were fewer other patents available to cite it (Lanjouw and Schankerman, 2004). As we explain in section 3, these observations are particularly relevant for the construction of our dependent variable.

How could the presence of a university incubator affect patent quality? Our analysis begins with the observation that universities, like other organizations, are bundles of resources, routines, and capabilities (Barney, 1991; Penrose, 1959). A university incubator does not operate in isolation, but is part of a university's overall portfolio of innovative activities. From a resource-based or capabilities perspective, the creation of an incubator should have a positive net effect on university innovation if it leverages resources and capabilities that are not fully exploited by the uni-

[4] For direct evidence that patent value is well approximated by forward citations, see recent work on patent auctions, a direct setting for measuring patent value. This work shows that forward citations are a strong predictor of the auction price paid to acquire a patent (Fischer and Leidinger, 2013; Sneed and Johnson, 2009).

versity’s other innovative activities such as research facilities and personnel and the technology transfer office (Lockett et al., 2005). Some university resources, such as land and buildings, are not easily divisible, creating the potential for excess capacity. Establishing an incubator can be an effective way of leveraging underutilized resources.

The presence of a university incubator can also create value by encouraging knowledge flows between academic researchers, students, and commercial firms that become incubator tenants (Rothaermel and Thursby, 2005b), increasing the likelihood of university personnel developing valuable, patentable innovations. Moreover, the presence of an incubator reduces the marginal cost for university personnel to establish their own ventures and become incubator tenants, increasing the incentives to generate high-quality patents. Over time, these knowledge flows and learning effects suggest that innovative capabilities may increase. For all these reasons, the presence of a university incubator should lead to higher quality, patentable innovations, suggesting a positive relationship between the establishment of a campus incubator and the patent citations flowing to the focal university.

If universities are resource constrained, and the effects of competition for resources outweigh the benefits of encouraging knowledge flows and capability development, then the net effect of establishing an innovator could be to reduce the quality of innovation. Incubators require resources: buildings must be constructed or expanded and maintained, personnel and operating funds must be allocated, and so on. These resources could also be devoted to other campus organizations and activities that encourage innovation, such as research facilities and personnel, training, and the technology transfer office. If the opportunity cost of devoting these resources to an incubator outweighs the benefits from incubation, the net effect of the incubator on university-based innovation will be negative. In short, the presence of an incubator could drain resources from other campus activities that encourage innovation, leading to lower-quality patenting at the expense of new firm formation.

The theoretical literature on university innovation does not offer much guidance about which effect is more likely, so we turn to the data to examine the net effect of establishing a university incubator on patent quality. This leads to our main hypothesis:

> *H1: The presence of a university incubator increases the quality of university-owned patents, other things equal.*

The alternative hypothesis is that incubators and patent quality are substitutes, not complements, in which case we would find a negative relationship between the presence of an incubator and patent citations, other things equal.

3. Methods

The general form of the empirical model we specify in order to test the two competing hypotheses is:

$$y_{it} = X_{it}\beta + \sum_i a_i A_i + \sum_t \gamma_t \Gamma_t \qquad (1)$$

where y_{it} refers to a modified version of the number of forward citations received by a given patent submitted by university i in year t (FORWARD). X_{it} is a vector of explanatory variables, described below. The summation symbols represent university-specific and year-specific dummy variables.

Because the number of forward citations depends on the age of the patent, we form our dependent variable as the number of forward citations received by the sample patents as of the end of 2012 expressed as a proportion of the average number of citations received by all patents granted in the same year. Thus, for any given year the average patent will have a FORWARD value of 1. A value of 2 indicates that the patent in question garnered twice the average number of forward citations, while a value of 0.5 would indicate it received only half the average number, and so forth.

To test the impact of incubators on patent quality we include a dummy variable (INCUBATOR) that takes the value of 1 if the application year of the focal patent is after or overlaps with the opening year of the university incubator and 0 otherwise.[5] For universities that never established incubator facilities, the variable at hand takes the value of 0 for all patents. A positive sign of the associated coefficient would provide support for the hypothesis that incubators increase the quality of innovation on campus, while a negative sign would indicate the opposite.

Prompted by previous findings that experience in patenting is instrumental for university patent quality (Mowery et al., 2002), we also include two variables to capture university experience. The first variable, EXPERIENCE, measures the number of patents granted to the focal patent's university from 1969 up to the grant date of the focal patent. We expect a positive sign for this variable. The second variable, FOREXPERIENCE, is designed to capture the university's experience in producing quality patents. It measures the average number of forward citations for the sample patents of the focal university (applied before the focal patent) as a proportion of the average number of citations received by all patents granted in the same year. Given path dependencies (Teece et al., 1997), we expect a positive sign for this variable.

Following previous literature (e.g. Czarnitzki et al., 2011; Sapsalis et al., 2006) we include several control variables in the analysis. First, we add the number of inventors and assignees in a

[5] A more precise measure of the potential effect of incubators on patent quality would be to construct the INCUBATOR variable employing the patent application date and the opening month and day of the incubator. This is an exercise we are presently pursuing. As an interim solution we performed the following tests: (a) we constructed the variable by defining the founding year of the incubator as $t - 1$ and then as $t + 1$, where t is the actual founding year; and (b) we restricted the observations of INCUBATOR that take the value of 1 only to those whose application year is strictly greater than the founding year of the incubator. While only suggestive, the empirical results of these exercises yielded almost identical results to those of our baseline specification.

given patent (INVENTORS, ASSIGNEES). Collaborative efforts generally enhance patent value, so we expect positive signs on the coefficients of both variables. We also include three patent-specific variables. The first measures the number of non-patent references (academic literature, government reports, and so on) included in the focal patent (NONPATENTREF). The second depicts the number of patents listed in the references list of a given patent (PATENTREF). Based on previous findings we expect non-patent references to be negatively associated with patent quality and the opposite for patent references (Sapsalis et al., 2006). Moreover, because patents that span a wide range of fields are often more valuable than more narrowly focused patents, we include the number of different four-digit International Patent Classification categories assigned to the focal patent (SCOPE) as an indicator of scope (e.g. Gans et al., 2008; Harhoff et al., 2003). We expect a positive sign on the coefficient for scope.

Finally, we include a set of university-specific dummy variables to account for unobservable characteristics of particular universities that might influence the quality of their patents. These include the underlying quality of the university faculty, the organizational structure of the academic institution, the effectiveness of rewards that encourage patenting, and the general attitude among the faculty members towards the commercialization of research via patenting. Along the same lines, to account for year-to-year fluctuations that can also influence patent quality we incorporate in the analysis a set of year-specific dummy variables. Such fluctuations may reflect, for instance, breakthrough scientific discoveries that disseminate slowly and influence a number of subsequent patents.

Before presenting our data and sources in detail we note two significant considerations that relate to our modeling choices and the overall study design. First, we include in our sample only incubators with a physical presence on campus (i.e., a stand-alone building or location in another university building) whose primary function is to assist faculty members with entrepreneurial projects and are formally tied to the particular university.[6] We exclude from the analysis "virtual" or "soft" incubators that typically assist recent graduates in starting businesses by providing small soft loans. We focus on physical, campus incubators based on a) the theoretical expectation that these types of incubators are more likely to be sharing university resources with activities that could also support patenting (leading to a negative relationship between incubators and patent quality) and b) the behavioral assumption that these types of incubators are more likely to generate knowledge flows towards university-based investors (leading to a positive relationship).

The second consideration refers to our definition of "university" we employ and the implications of that definition for our empirical strategy. For universities with one main campus, which comprise the majority of the academic institutions in our sample, the definition is straightforward. For universities that are part of a system (in particular, the University of California and State University of New York systems), the unit of analysis could be either the system or the individual campus. There are practical implications of adopting each definition. If there are significant knowledge flows across campuses within system universities, and if patenting or/and incubation activities are influenced heavily by the central administration, then treating campuses from the same system as one university seems appropriate. Defining universities by campus emphasizes local-decision making but assumes that knowledge flows and overall direction are confined within campuses. In our baseline estimates we consider system universities as one: across system universities, the INCUBATOR variable takes the value of 1 for patents applied after the founding date of the first incubator established in one of the system universities. For a robustness check we also present results in which observations from system universities are omitted.[7] As explained in

[6] This is not to imply that such incubators only host faculty entrepreneurs but to emphasize that faculty entrepreneurs tend to be core in the cohort of incubators we study.

[7] For patents of system universities the assignee is the system (e.g. University of California), so we treat these patents as belonging to the system, not the individual campus. We are in the process of manually assigning these to individu-

section 5, in these robustness checks the main conclusions remain similar to those of the baseline estimates.

4. Data

In our regressions the unit of analysis is the patent. To construct our sample we begin with the 62 members of the Association of American Universities (AAU) as of 2012. We excluded the two Canadian members of AAU to have a set of universities more comparable in terms of the motives and means to support incubators and patenting. Of the remaining 60 universities, 6 are members of the University of California system and 2 of the New York state university system. As explained above, we treat the system universities as one, reducing the 60 to 54. We were unable to obtain information for one remaining school, the University of Oregon, so we work with a final sample of 53 universities.

To source the patent data for each university in the sample we searched the patent database maintained by Thomson Innovation using the name of each sample university; we then retrieved information on patent application and grant dates, the number of forward citations, and the list of inventors and assignees to construct the variables described above. The resulting dataset includes information on every patent granted by the United States Patent and Trademark Office (USPTO) from 1969 through 2012 in which one of our focal universities was listed as the assignee. For each sample patent, forward citations are measured as of December 2012. We collected information on campus incubators, including founding dates, from university websites, Lexis-Nexis and other news databases, and direct contacts with universities and their technology transfer offices.

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al campuses based on the location of the relevant personnel, and in future work will define each system campus as a separate academic institution.

The final dataset features 55,919 patents granted from January 7, 1969 to December 25, 2012. (The corresponding application dates are March 29, 1957 to May 29, 2012.) Figure 1 shows the numbers of patents granted and incubators established during each of our sample years.

---Figure 1 about here---

As seen in Figure 1, the last four decades have witnessed a secular increase in university patenting, and university incubators have been also been established with increasing frequency. The number of patents per year increases steadily until 1999, stays at high levels with small yearly deviations from 2000 to 2009, and picks up again in 2010. From 1969 to 1989 the sample universities patented 306 inventions per year, on average; the corresponding figure for the 1990–99 period is to 1,534. Since 2000 the AAU universities as a whole have patented 2,627 inventions per year. The establishment of incubators proceeds more unevenly but 80 percent (33 of the 41) started after 1999. Interestingly, this is also the period in which patenting is becoming a university priority.[8] Purdue established the first university incubator in 1961, followed by Georgia Tech nearly two decades later in 1980.

Descriptive statistics are provided in Tables 1, 2, and 3. Table 1 presents the number of patents per university across the study period.. The University of California system is by far the most prolific patenter with 8,231 inventions, nearly 15 percent of the total for the entire sample. The most patent-intensive single campus is MIT, with its patents accounting for 7.5 percent of the sample patents. The University of Texas at Austin, Stanford, and Cal Tech round out the top five, followed by a group of mostly land-grand universities with more than 1,000 each.

[8] Ten of our sample universities did not have an incubator by the end of 2012: the University of Virginia, Brandeis University, California Institute of Technology, Carnegie Mellon University, Columbia University, Duke University, Emory University, Tulane University, the University of Pennsylvania, and Washington University in Saint Louis. Duke University is close to Research Triangle Park, but even when we classify that as a Duke incubator, the results are qualitatively similar to our baselines estimates.

--- Table 1 about here---

Table 2 summarizes the variables we use in the analysis. The dependent variable, forward citations normalized by the total for that year, is skewed, with a mode of zero: most university patents in our sample did not receive any forward citations. As indicated by the difference between the standard deviation (1.81) and the mean (1.0, by construction), there is significant variability in forward citations. Before getting the focal patent, our sample universities had, on average, been granted 1,247 patents with 3 inventors and 1 assignee. Most patents were listed under one 4-digit IPC code and had, on average, 15 and 22 patent and non-patent references, respectively. Note that the modal values of 0 both for PATENTREF and NONPATENTREF come mostly from early patents of the 1960s and the 1970s. More recent patents tend to have more extensive lists of backward references. Indeed, the differences in the backward references are strongly indicated by the large standard deviations of PATENTREF and NONPATENTREF compared to their mean values. Finally, more than 25 percent of the sample patents (14,180 of the 55,919) were applied for after the host campus established its incubator.

--- Table 2 about here---

As seen in Table 3, the correlation coefficients of the variables used in the analysis are relatively weak (the largest is 0.366) which should help us to estimate the net effect of each of the independent variables on the value of university patents.

--- Table 3 about here---

5. Results

We start with a series of OLS regressions, reported as our baseline estimates in Table 4. Each of the four specifications presented includes a different configuration of year and university dummy variables: none, year only, university only, and both. For all the estimates we report heteroskedasticity-consistent standard errors. The fit statistics at the bottom of Table 4 indicate that all four models have reasonable explanatory power, though they explain a rather limited portion of the observed variance. Joint significance tests for the dummy variables suggest that these variables are jointly statistically significant. The multicollinearity index is somewhat inflated in models 3 and 4, above the threshold level of 30, yet well below the worrisome level of 100 (Belsley et al., 1980). Elevated condition indices could inflate the standard errors and subsequently impact inference. Nevertheless, the inferences in models 1 and 2, which have lower multicollinearity indices, and in models 3 and 4 are almost identical, indicating that multicollinearity does not hamper our estimates materially. On the whole, the estimates from the four specifications are similar.

--- Table 4 about here---

In all four models the coefficient on INCUBATOR is negative and statistically significant, suggesting that average patent quality falls following the establishment of a university incubator. In model 4, which we use for our baseline estimates going forward, the coefficient on INCUBATOR implies that patents applied for after the establishment of an incubator receive 0.076 percent fewer forward citations than the average number of forward citations accumulated by all patents applied in that year. Besides the statistical significance, the size of that coefficient is also meaningful. To illustrate, consider the following hypothetical scenario: Assume that a given patent applied for before the establishment of the incubator has accumulated as many forward citations as the average number of forward citations accumulated by all patents applied in that year (hence the dependent variable takes the value of 1). Ceteris paribus, for an identical patent applied after the establishment of the incubator, the number of forward citations would be 92.4 percent of the average number of citations accumulated by patents from the same year.

The results for the experience variables are particularly interesting. While the focal university's overall experience in patenting has a positive and statistically significant effect on patent quality, its economic magnitude is tiny, suggesting that university experience has a limited impact on patent value. What appears to matter more is the experience of universities in producing higher-quality patents. Patents coming from universities with previous high-quality patents received close to 10 percent more forward citations than the average citations of same-year patents.

The variables that capture the effects of collaboration suggest that patents with more inventors tend to be more valuable. On the other hand, contrary to expectations, patents with more than one assignee (for the majority of cases these are patents owned by 2 or more universities) receive fewer citations. Finally, the control variables we use in the analysis imply that a) patent scope does not have a significant impact on patent value, b) an increased number of patent references is associated with more forward citations, and c) the number of non-patent references has a statistically significant but economically unimportant negative impact on university patent value.

To test the robustness of our findings we perform a series of checks which are presented in Table 5.[9] For parsimony these tables present only the models without dummy variables and with both university and year dummy variables. In models 1 and 2 of Table 5 we omit patents held by the University of California and State University of New York systems, to see if the results are sensitive to our definition of universities described in section 3. The estimates are nearly identical to those reported in Table 4 in terms of sign, magnitude and statistical significance. For instance, the estimate for INCUBATOR in the baseline model is −0.076 and the corresponding figure for

[9] Besides the robustness checks we present here, we have performed additional tests which are available upon request. These tests include: (a) omitting from the analysis the 835 patents that are owned by more than one sample university and thus enter the baseline analysis more than once; (b) replacing the dependent variable with the number of forward citations and including patent age as a right hand side variable; (c) performing stepwise regression where the INCUBATOR variable enters the analysis first followed by the remaining variables; and (d) including separate dummy variables for patents from universities that are part of university systems. In all these tests, the results are nearly identical to the baseline estimates and further reinforce our main conclusions.

the model with the reduced sample is −0.080. In short, defining universities at the system level does not substantially affect our results.

--- Table 5 about here---

For another check, we replace our continuous dependent variable with a binary variable and run a Tobit model. Our baseline estimates are obtained using OLS, which ignores the skewness and left truncation of our dependent variable, a percentage with a lower bound of 0. In fact, slightly more than 21 percent of our dependent variable observations take the value of 0. In models 3 and 4 of Table 5 we use a different specification with a dichotomous dependent variable taking a value of one if the patent has any forward citations and zero otherwise, running Tobit models to see if the OLS feature of ignoring the lower bound of our dependent variable is distorting the results. In tables 3 and 4 we present both the Tobit estimates and the marginal effects which are estimated with the right-hand variables held at their mean values. The marginal effects of the Tobit estimates are somewhat larger than the baseline estimates but mostly within the same range; the variable signs of all the models are identical and the statistical significances are very similar. This supports our basic conclusion that the presence of incubators is detrimental to university patent value and that previous university experience in quality patents influences the quality of later patents.

Our analysis explains patent quality in terms of the presence of incubators and university-specific dummy variables that attempt to capture the scientific talent of university faculty, which should also influence patent quality. However, faculty quality at a given university is typically not time-invariant, due to learning by existing faculty and the addition of new faculty. As such, university-specific dummy variables may not fully capture scientific talent over the sample period. This creates an endogeneity concern if scientific talent is related to the establishment of incubators (i.e. universities establish incubators only when they have promising faculty or projects in house), and scientific talent is not adequately measured (with the unobserved part ending up in the error term). To account for such potential endogeneity, we need an instrument that is correlated with the decision of a given university to establish an incubator and uncorrelated with the scientific talent of the focal university.

Following techniques and underlying principles used in the literatures on organizational restructuring (e.g. Campa and Kedia, 2002; Klein and Saidenberg, 2010) , we assume that a university's decision to establish an incubator is influenced by the behavior of its peers. We thus construct an instrumental variable for the establishment of each university's incubator at time *t* as the number of incubators established at or before time *t* at peer institutions.[10] We define peer institutions as those sample universities in either the same state of the focal university or an adjacent state. The presence of incubators in nearby institutions may influence the decision to establish an incubator, reflecting a form of institutional isomorphism (Meyer and Rowan, 1977; Powell and DiMaggio, 1983; Stensaker and Norgård, 2001) , but should be unrelated to the scientific talent of the focal university. Indeed, the correlation coefficient of the instrumental variable and the INCUBATOR variable is 0.62, which lends support to our theoretical contention.

The estimates from the IV estimation are presented in models 5 and 6 of Table 5. The results are very close to the baseline results reported in Table 4 in sign and statistical significance. For most of the coefficients the magnitudes are also similar. For instance, the coefficient for INCUBATOR in Table 6 is −0.138, while the corresponding coefficient in the baseline estimates is −0.076. Therefore, potential endogeneity does not appear to neither influence our estimates significantly nor to alter our main conclusions. Nevertheless, the IV estimates imply that our base-

[10] When constructing the instrumental variable using only incubators that were established before the establishment year of the focal incubator we obtain qualitatively similar results.

line estimates may represent a lower bound of the (detrimental) effect of incubators on patent quality.

6. Conclusion

University incubators, like other technology business incubators, are generally seen as effective mechanisms for translating academic research into commercially useful innovations and value-adding start-up companies. Indeed, some incubators, like Georgia Tech's—the second-oldest among AAU universities—have an impressive record (Rothaermel and Thursby, 2005b) in spawning new ventures, contributing to innovation and local economic growth. But most of the existing literature on incubators looks at an incubator's outputs, not the change in the university's overall innovative performance before and after an incubator is established. Even if incubators generate useful and commercializable knowledge, they may also compete with other university programs that also attempt to foster innovation and generate revenue.

Our work complements previous literature that demonstrates the positive contributions of incubators on innovation (Colombo and Delmastro, 2002; Kolympiris and Kalaitzandonakes, 2013; Markman et al., 2004) by suggesting that such contributions may come at the expense of other, equally valuable academic innovative activities. Specifically, we find that the establishment of a university incubator is followed by a decline in the average quality of the university's patents, controlling for patent-, university-, and time-specific characteristics. The results hold while also controlling for the potential endogeneity of the decision to establish an incubator.[11]

[11] Unfortunately we cannot tell which of a university's patents are specifically associated with its incubator, to see if the incubator's patents are better than those the university was producing before the incubator was set up, even while the average quality of the university's patents falls once the incubator appears.

To be clear, our results do not imply that incubators destroy value, as university incubators serve many purposes, educational as well as commercial.[12] The presence of an incubator may attract particular kinds of faculty and students, enhance the prestige of the university, and benefit the community as a whole. Because we do not measure these other outcome variables, or capture positive spillovers more generally, we cannot quantify the net effects of university incubators on innovation as a whole. However, much of the public discussion around incubators focuses on their specific impact on patenting, which generates licensing and other revenues. The decision to establish an incubator should thus be informed by reliable estimates of these specific effects. Our results suggest that university incubators may not generate net benefits for campus innovation. These are important findings for university administrators, policy makers, and remaining stakeholders who seek to promote innovation via the commercialization of academic research.

Our work also has a number of implications for innovation research. The literatures on incubators and academic patenting have, for the most part, grown in parallel. Here, we show that there are grounds for integration. As such, new works can explore in depths the interactions between incubators and university patenting. Another promising avenue for future research would be to examine more closely the specific mechanisms by which incubators affect university-based innovation, along the lines of Rothaermel and Thursby (2005a,b). Similarly, qualitative work can shed new light on the effect of academic entrepreneurs on the relationship between incubators and patent quality.

[12] An OECD handbook on incubators urges universities not to emphasize the educational aspects of their incubators, however. "[When universities are closely involved in the set-up of the incubator, there can be a conflict of views on the role of the incubator as a training tool (i.e. the view of education policy) and as a generator of high-potential start-ups (i.e. the view of business support policy). These approaches need to be reconciled, bearing in mind that a business incubation program that has a purely educational function is questionable and likely to produce poor value for money, though training and mentoring do play an important role in this policy. . . . When incubators are established within campuses, there is a danger that a wrong message about the contents of the program is transmitted to potentially interested participants. The incubator management will have to make it clear that training and teaching for tenant firms is of practical rather than academic nature" (OECD, 2010 pp 5)

Our study has a number of limitations that can be addressed in future work. First, as noted above, we look only at patent quality as the main effect of a university's innovative activities, rather than a broader set of impacts. Second, as noted in the data section, we treat university systems as single campuses, instead of assigning patents and incubators to specific campuses within these systems. Third, we have not included as regressors variables such as scientific complexity that can also impact patent value.

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Table 1. Patents per University from 1969 to 2012

University	Number of patents	Percentage of total patents	University	Number of patents	Percentage of total patents
University of California	8231	14.72	Northwestern University	704	1.26
Massachusetts Institute of Technology	4184	7.48	Penn State	691	1.24
University of Texas	2559	4.58	University of Pittsburgh	654	1.17
Stanford University	2556	4.57	WUSTL	633	1.13
California Institute of Technology	2349	4.20	Rutgers	616	1.10
University of Wisconsin	2199	3.93	Ohio State University	602	1.08
John Hopkins University	1716	3.07	Princeton University	584	1.04
Cornell University	1515	2.71	Texas A&M	584	1.04
University of Michigan	1456	2.60	University of Iowa	577	1.03
University of Florida	1325	2.37	Yale University	577	1.03
Columbia University	1156	2.07	University of Colorado	472	0.84
University of Minnesota	1154	2.06	University of Rochester	465	0.83
University of Pennsylvania	1121	2.00	University of Missouri	431	0.77
State University of NY	1091	1.95	University of Virginia	426	0.76
University of Illinois	1090	1.95	Carnegie Mellon	422	0.75
University of Chicago	1013	1.81	Vanderbilt	418	0.75
Iowa State University	999	1.79	Boston University	415	0.74
New York University	984	1.76	Emory University	398	0.71
Georgia Institute of Technology	978	1.75	Case Western	370	0.66
Harvard University	962	1.72	Indiana University	306	0.55
University of Washington	943	1.69	Rice University	288	0.52
Duke University	847	1.51	Brown University	232	0.41
Michigan State University	837	1.50	University of Arizona	212	0.38
University of Southern California	830	1.48	University of Kansas	194	0.35
University of Maryland	785	1.40	Tulane University	145	0.26
Purdue University	780	1.39	Brandeis University	115	0.21
University of North Carolina	728	1.30			

Table 2. Descriptive Statistics

	Variable Description	Variable Code	Number of Observations	Mean	Std Dev	Median	Mode	Minimum	Maximum
Dependent variable	Number of forward citations for the sample patents expressed as a proportion of the average number of citations received by all patents granted in the same year	FORWARD	55919	1.00	1.81	0.43	0.00	0.00	51.93
Continuous variables	Number of patents granted to the university of the focal patent since 1969 up to the grant date of the focal patent	EXPERIENCE	55919	1246.70	1654.12	615.00	201.00	0.00	8228.00
	Average number of forward citations for the sample patents of the focal university expressed as a proportion of the average number of citations received by all patents granted in the same year	FOREXPERIENCE	55427	1.02	0.31	0.98	1.02	0.00	9.98
	Number of inventors	INVENTORS	55919	2.76	1.69	2.00	2.00	0.00	34.00
	Number of assignees	ASSIGNEES	55919	1.15	0.41	1.00	1.00	0.00	11.00
	Number of IPC categories	SCOPE	55863	2.26	1.55	2.00	1.00	1.00	18.00
	Number of backward patent references	PATENTREF	55919	15.52	30.83	8.00	0.00	0.00	837.00
	Number of backward non-patent references	NONPATENTREF	55919	22.09	44.51	8.00	0.00	0.00	1449.00
Binary variable	Variable that takes the value of 1 if the application year of the focal patent is after or overlaps with the opening year of the university incubator and 0 otherwise	INCUBATOR[a]	14180						

[a] For this variable the figure in the Number of Observations column presents the number of observations that take the value of 1

Table 3. Corrleation Coefficients between Variables Used in the Analysis

	FORWARD	EXPERIENCE	FOREXPERIENCE	INVENTORS	ASSIGNEES	SCOPE	PATENTREF	NONPATENTREF	INCUBATOR
FORWARD	1								
EXPERIENCE	-0.037	1							
FOREXPERIENCE	0.080	0.040	1						
INVENTORS	0.056	0.116	0.050	1					
ASSIGNEES	-0.006	0.037	-0.005	0.366	1				
SCOPE	0.051	0.024	0.025	0.140	0.094	1			
PATENTREF	0.095	0.091	0.036	0.109	0.071	0.080	1		
NONPATENTREF	0.008	0.086	-0.004	0.133	0.124	0.189	0.479	1	
INCUBATOR	-0.075	-0.152	-0.269	0.039	0.038	-0.019	0.051	0.057	1

Table 4. Baseline Estimates. The dependent variable is the number of forward citations for the sample patents expressed as a proportion of the average number of citations received by all patents granted in the same year

Variables / Model	1			2			3			4		
	Estimate	White's Standard Errors		Estimate	White's Standard Errors		Estimate	White's Standard Errors		Estimate	White's Standard Errors	
Intercept	0.429	0.042	***	0.332	0.044	***	0.537	0.085	***	0.414	0.087	***
Incubator	-0.090	0.018	***	-0.046	0.019	**	-0.104	0.030	***	-0.076	0.032	**
Forexperience	0.369	0.028	***	0.388	0.028	***	0.098	0.039	**	0.108	0.039	***
Experience	0.000	0.000	***	0.000	0.000		0.000	0.000	***	0.000	0.000	***
Inventors	0.061	0.007	***	0.063	0.007	***	0.062	0.007	***	0.061	0.007	***
Assignees	-0.085	0.028	***	-0.083	0.028	***	-0.059	0.028	**	-0.062	0.028	**
Nonpatentref	-0.001	0.000	***	-0.001	0.000	***	-0.001	0.000	***	-0.001	0.000	***
Patentref	0.012	0.001	***	0.012	0.001	***	0.012	0.001	***	0.012	0.001	***
Scope	0.006	0.006		0.002	0.006		0.009	0.006	*	0.005	0.006	
Year Dummies Included	NO			YES			NO			YES		
University Dummies Included	NO			NO			YES			YES		
Test of Joint Significance for Year Dummies		-			4.78	***		-			4.44	***
Test of Joint Significance for University Dummies		-			-			11.42	***		10.6	***
Adjusted R^2		0.048			0.049			0.056			0.058	
F - test of overall model significance		78.82	***		22.76	***		21.81	***		16.64	***
Multicollinearity Condition Index		13.865			16.156			42.689			45.901	
Number of Observations		54537			54537			54537			54537	

*** .01 significance, ** .05 significance, * .10 significance

Table 5. Robustness Checks. The dependent variable is the number of forward citations for the sample patents expressed as a proportion of the average number of citations received by all patents granted in the same year. Observations from system universities are ommitted.

Variables / Model	1			2		
	Estimate	White's Standard Errors		Estimate	White's Standard Errors	
Intercept	0.394	0.046	***	0.406	0.079	***
Incubator	-0.081	0.020	***	-0.080	0.032	**
Forexperience	0.374	0.029	***	0.206	0.038	***
Experience	0.000	0.000		0.000	0.000	***
Inventors	0.060	0.007	***	0.063	0.007	***
Assignees	-0.083	0.031	***	-0.057	0.031	*
Nonpatentref	-0.001	0.000	***	-0.001	0.000	**
Patentref	0.013	0.001	***	0.013	0.001	***
Scope	0.009	0.006		0.006	0.006	
Year Dummies Included	NO			YES		
University Dummies Included	NO			YES		
Test of Joint Significance for Year Dummies		-			5.79	***
Test of Joint Significance for University Dummies		-			10.84	***
Adjusted R^2		0.054			0.067	
F - test of overall model significance		78.1	***		17.56	***
Multicollinearity Condition Index		13.545			42.650	
Number of Observations		45283			45283	

*** .01 significance, ** .05 significance, * .10 significance

Table 5 continued. Robustness Checks. Tobit Model. The dependent variable is the number of forward citations for the sample patents expressed as a proportion of the average number of citations received by all patents granted in the same year.

Variables / Model	3			4		
	Marginal Effect	Tobit Estimate		Marginal Effect	Tobit Estimate	
Intercept						
Incubator	-0.180	-0.420	***	-0.170	-0.398	***
Forexperience	0.155	0.352	***	0.100	0.228	***
Experience	0.000	0.000	***	0.000	0.000	***
Inventors	0.026	0.059	***	0.031	0.070	***
Assignees	-0.067	-0.152	***	-0.041	-0.093	***
Nonpatentref	-0.001	-0.003	***	-0.001	-0.002	***
Patentref	0.006	0.014	***	0.007	0.015	***
Scope	0.006	0.013	**	-0.004	-0.009	
Year Dummies Included	NO			YES		
University Dummies Included	NO			YES		
Test of Joint Significance for Year Dummies		-			44.09	***
Test of Joint Significance for University Dummies		-			14.57	***
Sigma		2.099			2.058	
Pseudo R^2		0.0123			0.023	
LR test of overall model significance		2532.39	***		4732.35	***
Multicollinearity Condition Index		13.865			45.901	
Number of Left Censored Observations		11755			11755	
Number of Observations		54537			54537	

*** .01 significance, ** .05 significance, * .10 significance

Note: Marginal Effects are calculated at the means

Table 5 continued. Robustness Checks. Estimates employing an Instrumental variable for the establishment of incubators. The dependent variable is the number of forward citations for the sample patents expressed as a proportion of the average number of citations received by all patents granted in the same year

Variables / Model	5			6		
	Estimate	White's Standard Errors		Estimate	White's Standard Errors	
Intercept	0.488	0.049	***	0.565	0.064	***
Incubator	-0.245	0.041	***	-0.138	0.046	***
Forexperience	0.345	0.035	***	0.130	0.045	***
Experience	0.000	0.000	***	0.000	0.000	***
Inventors	0.056	0.007	***	0.056	0.007	***
Assignees	-0.066	0.030	**	-0.057	0.030	*
Nonpatentref	-0.001	0.000	***	-0.001	0.000	***
Patentref	0.014	0.001	***	0.014	0.001	***
Scope	0.008	0.006		0.007	0.006	
Year Dummies Included	NO			YES		
University Dummies Included	NO			YES		
Test of Joint Significance for Year Dummies		-			92.1	***
Test of Joint Significance for University Dummies		-			382.28	***
Adjusted R^2		0.051			0.0617	
Wald test of overall model significance		589.55	***		993.59	***
Multicollinearity Condition Index		14.286			44.587	
Number of Observations		47390			47390	

*** .01 significance, ** .05 significance, * .10 significance

Figure 1.
Number of Patents Granted to AAU Universities and Number of Incubators Started Each Year