Startup Firms from Research in U. S. Universities

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1. Introduction

As is well-known by now, the Bayh-Dole Act led to an explosion in technology transfer efforts by universities, as well as a substantial increase in the commercialization of university inventions. Technology transfer offices (TTOs) at U.S. universities are responsible for making good-faith efforts to commercialize university inventions. This process begins when a faculty member discloses a potential invention to the TTO, which then tries to find a partner for commercialization. The partner may be either an established firm or a new business venture (startup) funded independently by venture capitalists, angel investors, or the faculty inventor. Although initially most of this activity took the form of license agreements with established firms, there has been an increase in commercialization via new firms, or startups, with the passage of time.

This paper empirically examines university entrepreneurship in the form of the commercialization of faculty inventions through startup firms for the period 1994 through 2004. According to data collected by the Association of University Technology Managers (AUTM), for fiscal years 1993-2004, the number of startups emerging from U.S. universities increased by nearly 80 percent, and the average number of startups per university increased by about 45 percent. Several models are estimated of both the annual number of startups initiated per university and the annual cumulative number of operational startups per university. Generally speaking, annual startups initiated measures the number of new firms created in that year, while annual cumulative operational startups measures the number of all startups initiated at any time in the past that remain operational. Therefore, both can reasonably be considered as measures of the success of university research and technology transfer, but the former is perhaps best thought of as a necessary condition for this success, while the latter is a sufficient condition.

In this study the annual number of startups initiated and cumulative operational startups per university are modeled as a function of characteristics of the university itself, its faculty, and general financial conditions. I employ annual university-level data from the surveys by AUTM on the number of startups initiated and operational, the presence of a medical school, land-grant and private status, the size and age of the TTO, the number of invention disclosures, and the levels of federal and industrial funding, as well as data on the size and quality of the life science and engineering faculties from the 1994 Survey by the National Research Council (NRC). The quality measure is a weighted average of the NRC ranks of the individual department in each university, and varies from one to five. I also use annual state-level data on venture capital funding from the National Venture Capital Association Yearbook, and the annual NASDAQ composite index.

I test four different specifications of the model, involving four different samples: all U.S. universities in the AUTM surveys; all universities except the University of California (UC) system, omitted because all ten of its campuses report as one, so these observations are substantial outliers; all universities who created their TTOs before passage of the Bayh-Dole Act in 1980;[1] and all universities who created their TTOs after passage of Bayh-Dole.[2]

1 Those universities with TTOs created before the passage of the Bayh-Dole Act are: Boston, Colorado State, Cornell, Harvard, Iowa State, Johns Hopkins, Kansas State, Montana State, Oregon State, Stanford, Tufts and Washington State Universities, the California and Massachusetts Institutes of Technology, the State University of New York system, the University of California system, and the Universities of Georgia, Iowa, Minnesota, Rochester, Southern California, Utah, Virginia and Wisconsin.

2 I thank Bruno Cassiman for suggesting that I stratify the data by the ages of the TTOs in a different context. There is insufficient data to allow for finer partitions by TTO age, but using the Bayh-Dole Act to partition the data seems the most reasonable and intuitive approach.

The results are interesting from several perspectives. First, the main result for the annual number of startups initiated per university is that it is positively related to the quality of the engineering faculty, the levels of federal and industrial funding, the number of invention disclosures of the university, and the level of venture capital funding in the state where the university is located, while negatively related to whether the university is private and whether it has land-grant status.[3] The number of startups initiated is also negatively related to the NASDAQ index in the sample that omits the UC system and the sample of universities with newer TTOs. However, as discussed in detail in Section 5, the magnitude of the effect for most of these variables is small, in that the increase in the variable required to induce one additional startup per year is large, compared to the sample mean. Conversely, one exception is private status, which generally implies one less startup every two years in the full sample, and roughly four fewer startups per year in the sample omitting the UC system and three fewer startups per year in the sample of universities with newer TTOs. The effects of land-grant status are the same in magnitude.

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3 Land-grant institutions are colleges or universities in the U.S. designated by their state to receive the benefits of the Morrill Acts of 1862 and 1890. Under the acts, each state received a grant of federal land to be used to develop educational institutions to focus on teaching agriculture, science and engineering. The first act was the outcome of a political movement emphasizing both the need for more agricultural and mechanical education and the need for greater access to higher education (Nemec 2006). Some institutions that received land-grant status already existed in 1862, such as MIT and Rutgers, while others were created afterward. See the web site of the Association of Public and Land-grant Universities (www.aplu.org) for a list of the 76 land-grant institutions.

Next, in general, the number of cumulative operational startups per university is positively related to the quality of the engineering faculty, the age of the TTO, the level of industrial funding, and the number of invention disclosures in the university, but negatively related to the land-grant and private status of the university. Again, the magnitude of the effect for many of these variables is small, but there are notable exceptions. As detailed in Section 5, the increase in the NRC ranking of a university's engineering faculty required for one additional operational startup is very small in the sample omitting the UC system. Similarly, a very small increase in the ranking of a university's life science faculty is needed for one additional operational startup in the sample of universities with newer TTOs. Private status implies six fewer operational startups in the sample that omits the UC system, and five fewer operational startups in the sample of universities with newer TTOs. Land-grant status implies four and three fewer operational startups in these two samples, respectively.

These results have implications for university administrators or policymakers who are interested in generating more startups. First, as the relative sample sizes indicate, in any given year the number of all startups that remain operational is generally less than half of the startups initiated in that year. Thus, although startups must be initiated to become operational, it seems apparent that the cumulative number of startups that remain operational deserves more attention as a metric of success. The results for this measure largely indicate that those universities with older TTOs, and more experience in technology transfer, should simply continue what they are currently doing.

By contrast, those universities with newer TTOs, and less experience in technology transfer, can increase their startup activity with relatively small increases in the quality of their life science and engineering faculties (as measured by the NRC rankings), the level of industrial funding, and the number of annual invention disclosures. The results also show that startup activity for these universities increases with small increases in the age of their TTO, and is higher for those which are not private. The former result suggests substantial learning-by-doing in university startup activity. Although this learning process can be sped up with the hiring of more experienced staff for the TTO, this may have limited effect because university faculty and administration also need to learn about the process of technology transfer. Similarly, a private university cannot, in general, simply choose to become public. Many private universities need to overcome a culture that has not been conducive to technology transfer via startup firms involving their faculty.

Perhaps the most important contribution of this analysis is the recognition that the UC system is an outlier whose inclusion in the data causes substantial differences in results, and that the universities with newer TTOs are dramatically different from those with older TTOs (including the UC system). Increases in the size and quality of the engineering faculty, the size of the life science faculty, the number of invention disclosures, the level of industrial funding, and the age of the TTO, and decreases in the NASDAQ index, are all more likely to have beneficial effects on startup activity when the UC system is omitted from the analysis. These beneficial effects are even more pronounced for those universities with TTOs created after the passage of the Bayh-Dole Act. The results that emerge from this partitioning of the data indicate that startup activity depends crucially on a university's past success, or perhaps more accurately, lack of past success in technology transfer.

2. Literature review

These results contribute to a small but growing literature on university entrepreneurship and startups. Rothaermel, Agung, and Jiang (2007) provide a very thorough review of the literature. For the purposes of this paper the focus is on the most closely related work.

First, there is a small theoretical literature that has predominantly focused on the behavior of faculty in the research, disclosure, and commercial development of university inventions, and the behavior of technology transfer officers in licensing those inventions: Jensen and Thursby (2001), Lach and Shankerman (2002), Jensen, Thursby, and Thursby (2003), Thursby, Thursby, and Decheneaux (2004), Hoppe and Ozdenoren (2004), and Macho-Stadler, Perez-Castrillo, and Veugelers (2004).

The empirical literature on university invention is more extensive, but often focuses on case studies of specific universities that have provided exceptionally detailed data sets. For example, Shane studies startups based on inventions by MIT faculty. He shows that startups are more likely when inventors recognize business opportunities (Shane 2000) or technological opportunities (Shane 2001), and that licensing to inventor-startups is more likely when patents are ineffective at preventing information problems such as moral hazard and adverse selection. However, he also finds that licenses to startups perform poorly compared to licenses to established firms. Similarly, Lowe and Ziedonis (2004) use data from the University of California to show that royalties from startups are higher on average, but successful commercialization tends to occur only after acquisition by an established firm.

There are three more general studies of startups using AUTM data. Di Gregoriao and Shane (2003) study startups from US universities using AUTM data for 1994 to 1998, finding a positive relationship between startup formation and faculty quality, as measured by the Gourman Report. O'Shea et al. (2005) also study startups from U.S. universities using AUTM and NRC data for 1995 to 2001, finding positive relationships between startups and faculty quality (measured by NRC rankings), faculty size, federal funding for science and engineering, past success in startups, a high fraction of industry funding, and TTO size. The following study extends these analyses by using data through 2004, using measures of university faculty size in the life sciences and engineering, adding financial variables, using time (annual) fixed effects, analyzing the annual number of cumulative operational startups as well as startups initiated, and partitioning the data in new ways. This study often finds different results, as noted below.

Another related work is the unpublished manuscript by Chukumba and Jensen (2005), which develops a theoretical model to explain when university technology is licensed to startup firms versus established firms. This is accompanied by reduced form estimates of the number of startups initiated and licenses to established firms. The estimation of startups in that working paper uses licensing revenue as a proxy for past success, thus introducing serious endogeneity concerns. Again, this study finds results that are often different, as noted later.

3. Data

Generally the commercialization of university inventions is a process that begins with the faculty conducting research, given funding from various sources, that results in disclosures to the university's technology transfer office (TTO) or office of technology licensing. A disclosure is a relatively short form that describes the invention and suggests possible commercial applications. The TTO then attempts to find a firm to partner with in attempting to develop the invention for commercial application. Generally the university and firm enter a license (or option) agreement for use of the invention. The licensee generally pays the costs of patenting, often provides additional funding for the inventor's research, pays the costs of the further development typically required for commercial application, and commits to pay a stream of royalties if the invention is a commercial success. In this event, the university shares this stream of license revenue with the faculty inventor(s). As shown in Jensen and Thursby (2001), this feature of the Bayh-Dole Act provides a substantial incentive for inventors to engage in the development process, thereby increasing the likelihood of discovering a successful commercial application. Indeed, often the licensing agreement involves a startup firm in which the faculty inventor is a principal.

For each university, the annual measures of entrepreneurship are startups initiated and cumulative operational startups. These outcomes are discrete (integer-valued), of course. The data are provided by AUTM, which has published surveys including startup data for the years 1994 through 2004. This is an unbalanced panel ranging from 145 U.S. universities and 31 U.S. hospitals and research institutes in 1994 to 164 U.S. universities and 33 U.S. hospitals and research institutes in 2004.

We consider explanatory variables that include characteristics of the TTO, the faculty, and the university. The literature generally argues and finds support for the hypotheses that the effectiveness of a TTO depends on its experience and expertise both at eliciting disclosures from faculty and at locating potential partners for the inventions (see, e.g., Thursby, Jensen, and Thursby 2001 and Jensen, Thursby and Thursby 2003). For each university, AUTM provides data on TTO size (ttosize), measured as the number of full-time equivalents (FTEs) devoted to licensing activities, and TTO age (ttoage), measured by the number of years since the university first devoted at least one half of an FTE to its licensing activities. The rationale for using the size of a TTO is that larger TTOs not only have greater resources, but also may have more experience among their personnel. The rationale for using the age of a TTO is that older TTOs have more experience and expertise.

Next, the size and quality of the faculty must impact the startups arising from university intentions. Previous studies have used the National Research Council's Survey (1994) to construct a quality measure for each university's faculty as a whole, or for its faculty in the life sciences and engineering. These measures are obviously flawed in that they measure quality at a single point in time, and they can be constructed only for those universities with doctoral programs. However, they are reasonable to the extent that the faculty sizes and program rankings do not change too much over time, and these measures have typically had explanatory power in other previous studies. Specifically, for each university in the AUTM survey data, we determine the total number of faculty in all engineering doctoral programs (engsize), then compute the size-weighted average of the NRC faculty quality score (Q93A) for those programs, which we use as a measure of engineering faculty quality (engqual). We do the same for each university's life science doctoral programs to obtain the size (scisize) and quality (sciqual) of its science faculty.

General university characteristics also may influence success in technology transfer. For example, nearly all prior studies have tested the hypothesis that the presence of a medical school or status as a land-grant institution should matter to technology transfer because faculty inventions from these universities should be generally closer to commercial application. Another university characteristic that should matter is whether it is private or public. Whether they have land-grant status or not, public universities are expected to contribute to local and regional economic development. Therefore, faculty inventions in public universities also may be closer to commercial application than those in private universities. Moreover, private universities may not have a culture conducive to commercialization of their research, as suggested by the fact that roughly three-fourths of private universities in the AUTM data did not create a TTO until after passage of the Bayh-Dole Act. However, some private universities, notably MIT and Stanford, are known for having a culture that encourages faculty-startups (Shane 2000 and O'Shea et al. 2005), so the net effect of private status on startups is not obvious, *a priori*. I represent these characteristics by the dummy variables medschool, landgrant, and private, each equal to 1 if the university has a medical school, is land-grant, or is private.

Because a university's research output, and the resulting technology transfer, depends upon its level of funding, I also include the current (annual) level of research funding for each university provided by the federal government (lnfedfnd) and by industry (lnindfnd). I use logged values due to the highly skewed nature of these variables. Disclosures are a key input to the technology transfer process, because research success cannot translate into technology transfer unless inventions are disclosed to the TTO. Because it takes time to move from a disclosure to a license (whether to an established firm or a startup), the lagged number of annual invention disclosures for each university is included (lagdisclose).

Finally, because university startups are usually funded by venture capitalists or angel investors, it is important to add some financial variables to indicate the availability of funding. I use both the annual level of venture capital spending in the state where the university is located (lnventcap), logged because its distribution is very skewed, and the annual change in the composite NASDAQ index (nasdaq). Intuitively, greater availability of venture capital funding should imply more startups, whereas increases in the NASDAQ index indicate better alternative opportunities for investors and so fewer startups.

Table 1 displays summary statistics. Roughly half of the universities in the AUTM data have medical schools, while about 30 percent are land-grant and another 30 percent are private. These characteristics are not mutually exclusive, of course, because medical schools are present at both private and land-grant universities, and some private universities have land-grant status. The NRC quality rankings use a scale from one to five (low to high), and the weighted averages span nearly the entire range. The data for the sizes of the life sciences faculty are substantially skewed because the UC system submits one report for all ten of its campuses. The means of science and engineering faculty size are 248 and 102, and the medians are 151 and 76. Similarly, the sizes and ages of the TTOs vary substantially, although the typical TTO is still small. Mean TTO size is 3.57

FTE, and the median is two. TTO age is also very skewed. The mean age is about 12 years, but there were 27 TTOs in existence when the Bayh-Dole Act was passed in 1980 (24 of which are included in the data). In fact, five universities have TTOs that were founded more than 50 years ago (Iowa State, Kansas State, MIT, Wisconsin, and the UC system). Annual federal and industrial funding per university are both extremely skewed, with values ranging from zero to two billion and 318 million (respectively). Annual venture capital spending in each state is even more skewed, ranging from zero to 43 billion.

Finally, both the annual number of startups initiated and cumulative operational startups are also skewed, though not as severely as the funding variables. However, it is most important to note that the annual number of startups is frequently zero. In particular, 809, or about 39 percent, of the 2054 observations are zero. The annual number of operational startups is less skewed, but this variable also takes the value zero about 15 percent of the time, or 148 of the 983 observations. The small number of observations (compared to startups initiated) is a clear indication of the high failure rate for university startups.

4. Empirical model and analysis

For each startup outcome and sample, the specification of the econometric model involves equations of the form,

$$Y_{it} = \alpha + \beta_1 X_{1it} + \beta_2 X_{2i} + \varepsilon_{it},$$

where i indexes universities, t indexes time, Y_{it} is a measurable outcome of university startup activity, X_{1it} is a vector of time-varying explanatory variables, X_{2i} is a vector of time-invariant explanatory variables, and ε_{it} is an error term.

For each of the explanatory variables in this model, causation arguably goes in the correct direction. However, concerns about endogeneity would remain if there are other variables omitted from the model that are correlated with both startups and some explanatory variable. I test four specifications for each startup outcome, each corresponding to a different sample. The first is a test on the full sample of all U.S. universities. The second is a test on the sample of all universities except the UC system. There are two reasons to omit the UC system. As noted, many of its observations are outliers because it submits one report for all ten campuses. Moreover, it also has both land-grant status and a medical school, although not all of its campuses fulfill either of these functions. The remaining specifications involve a partition of the data: the third test is for universities who created their TTOs before the passage of the Bayh-Dole Act in 1980, and the fourth test is for those universities who created their TTOs after the passage of the Act. I use a negative binomial specification for all of these regressions because, as previously noted the number of annual startups initiated and cumulative operational startups are count data that are both skewed and contain a non-trivial fraction of zeros.

Table 2 reports the results for the number of annual startups initiated per university. The first column reports the results for the full sample, and this is the benchmark case. The second column reports the results when the UC system is omitted from the data; the third reports the results for those universities with older TTOs (created before the passage of the Bayh-Dole Act in 1980); and the fourth reports results for those universities with newer TTOs (created after the passage of the Bayh-Dole Act in 1980). All specifications include time (annual) fixed effects.

First, the previous studies noted, which use less data, generally show no significant effect of a medical school, land-grant status, or private status on startup activity. This study tends to confirm these results for the presence of a medical school. Precisely, the number of annual startups initiated per university is negatively and significantly correlated with the presence of a medical school, but only for the sample of universities with newer TTOs, and only at the ten percent significance level. However, this study finds that the annual number of startups initiated is negatively and significantly correlated with whether a university has land-grant status in all samples, and is negatively and significantly correlated with whether a university is private in all samples except universities with older TTOs. In terms of initiating startups, private universities that became involved in the technology transfer process before the passage of the Bayh-Dole Act do not differ significantly from their public counterparts, but those who became involved after the passage of the Act do. Private universities that did not create TTOs until after 1980 apparently do not have a culture encouraging technology transfer. And, because universities with land-grant status are generally considered to produce inventions that are, on average, closer to commercial application, it may be that these universities are also more likely to find established firms as partners in technology transfer, and so have relatively less need for startups.

The number of startups is positively and significantly correlated with the quality of the engineering faculty, though, interestingly, this is generally the only faculty characteristic that matters. An exception is that startups are positively and significantly correlated with the size of the engineering faculty for the sample of universities with older TTOs, and again, this is not a surprise because these universities demonstrated a culture of encouraging technology transfer well before the passage of the Bayh-Dole Act. The other exception is that the number of startups is negatively correlated with the size of the life science faculty for the full sample, though only at the five percent level. Because this result is not robust to the other specifications, it is not clear how much emphasis should be placed on it. These results confirm those in Chukumba and Jensen (2005), but differ from O'Shea et al. (2005), who find a significant and positive relationship with science faculty quality (for fewer years of data) .

Next, the size, experience and expertise of the university TTOs do not seem to have any significant effect on the number of startups initiated. TTO size and age are each significant only for the sample without the UC system. Although both have the anticipated positive signs in these cases, they are significant only at the ten percent level. This again stands in contrast to the results of O'Shea et al. (2005), but tends to support the other studies which have found that TTOs are either less effective or less interested in finding partners for startups (e.g., Shane 2001, Lowe and Ziedonis 2004, and Chukumba and Jensen 2005).

The number of startups is also positively and significantly correlated with the lagged number of disclosures and levels of federal and industrial funding. This is as expected, of course, because each of these is a measure of inputs that are important to the process of technology transfer. The results for funding confirm those of Chukumba and Jensen (2005) and O'Shea et al. (2005), but they are not robust to the sample of universities with older TTOs. These universities are older, well-established ones whose funding levels did not vary that much over the time period, and have had a culture that encouraged the technology transfer process for many decades.

The results for the financial variables are rather interesting. The number of startups is positively and significantly correlated with the level of venture capital funding in the state where the university is located, except in the sample of universities with newer TTOs (created after passage of the Bayh-Dole Act). This is also as expected, because greater availability of venture capital funding locally should increase the likelihood that university startups can find the necessary funding (Chukumba and Jensen 2005 also find this for the full sample). However, because there is no significant effect for the sample of universities with newer TTOs, it appears that venture capitalists are reticent to deal with universities that are relatively new to the technology transfer process.

More interesting is the result that the number of startups is negatively and significantly correlated (at the five percent level) with the annual change in the composite NASDAQ index both for the sample of all universities except the UC system and the sample of universities with new TTOs. In these cases, more startups are associated with a falling NASDAQ, which is consistent with the view that investors are more drawn to university startups when their alterative investment opportunities are poor.

The annual number of startups initiated, of course, is perhaps best viewed as a measure of university research results that have just enough promise to attract funding from venture capitalists or angel investors. Alternatively, the annual number of cumulative operational startups is perhaps a better measure of the quality, or commercial success, of these research results, because it is the number of all startup firms initiated by the university at any time in the past that are still active in business. Table 3 reports the results for the number of cumulative startups that remain operational per university per year. Again, the first column reports the results for the benchmark case of the full sample, the second reports the results omitting the UC system, the third reports the results for universities with older TTOs, and the fourth reports results for those with newer TTOs.

As with startups initiated, the number of cumulative operational startups is negatively and significantly correlated with the presence of a medical school, but only at the ten percent level for the sample of universities with newer TTOs. And again, the number of operational startups is negatively and significantly correlated with whether a university is land-grant or is private, but private status has no effect in the sample of universities with older TTOs.

The results for size and quality of the engineering faculty are also similar to those for startups initiated. The number of cumulative operational startups is positively and significantly correlated with the quality of the engineering faculty both in the full sample and the sample where the UC system is omitted. It is positively correlated with the quality of the engineering faculty, but with weak significance (at the ten percent level), for the sample of universities with older TTOs. The lack of significance when the data is partitioned into universities by the age of the TTOs may simply be a function of the small sample sizes in these cases. And again, cumulative operational startups are positively and significantly correlated with the size of the engineering faculty when the sample is restricted to universities with older TTOs (and a history of embracing technology transfer).

One difference from the results for startups initiated, however, is that the size and quality of the life sciences faculty now matter. For the sample of universities with older TTOs, the number of cumulative operational startups is negatively and significantly correlated with the size of the life science faculty. This is a small sample, but among these universities with older TTOs, those with large life science faculties, *ceteris paribus*, have fewer operational startups. Moreover, the number of cumulative operational startups is positively and significantly correlated with the quality of the life science faculty both for the full sample and for those universities with newer TTOs. This suggests that, for these universities, high-quality life science faculty do not initiate as many startups as engineers, but a higher fraction of their startups survive over time.

As with startups initiated, the size of university TTOs does not seem to have any significant effect on the number of cumulative operational startups. TTO size is significant in none of the specifications. However, in stark contrast to the results for startups initiated, the age of the TTO is positive and significant in every specification except the sample of universities with older TTOs. This suggests that learning-by-doing by universities, their faculties, and their TTOs is important to the creation of startups that continue to operate successfully.

Again, the number of cumulative operational startups is, in general, positively and significantly correlated with the lagged number of disclosures and with the level of industrial funding. This is as expected, of course, because each of these is a measure of inputs that are important to the process of technology transfer. But the universities with older TTOs are again exceptions, as in their case lagged disclosures has no significant effect, and cumulative startups are negatively correlated with industrial funding (significant at the five percent level). Among this small group with very old and experienced TTOs, those universities with greater funding from industrial sources generate fewer operational startups. This may simply indicate that the sources of industrial funding are likely to be technology transfer partners (i.e., the funding may be tied to an option to license), so startups are less likely.

In contrast to the results for startups initiated, the number of operational startups is positively and significantly correlated to the level of federal funding only for universities with older TTOs. This suggests that, except for those universities with very old and experienced TTOs, greater federal funding may help to initiate more startups, *ceteris paribus*, but not ones that successfully survive.

The results for the financial variables also differ in this case. The number of cumulative operational startups is positively and significantly correlated with the level of venture capital funding in the state where the university is located for only the full sample and when the UC system is omitted. There is no effect when the sample is partitioned by the age of the TTOs. Thus, greater availability of venture capital locally, as expected, generally results in a larger number of startups that remain operational. The lack of effect in the case of universities with older TTOs may simply be a function of the small sample size.

Finally, changes in the composite NASDAQ index had no significant effect whatsoever on the cumulative number of operational startups. This is surprising because the number of startups initiated is negatively correlated with the annual change in the NASDAQ index, but this might also simply indicate that although poor alterative investment opportunities are helpful in providing funds to initiate university startups, they do not seem to be essential to the continuing success of those startups.

5. Interpretations

To provide additional context, marginal effects for changes in those explanatory variables that are significant in the estimations are computed. For each specification, marginal effects are computed at the means of the sample. For dummy variables, these effects show the change in the number of startups per university that would occur if that dummy variable changed from 0 to 1. In the case of those explanatory variables that are continuously valued, for the sake of concreteness, the question is: How large a change in this variable would be required to induce one additional startup per university?

For ease of exposition, the results are stated with the presumption that changes in the explanatory variables cause an effect on university startups. As noted above, this seems correct for my choice of explanatory variables, though the possibility of an omitted variables bias cannot be ignored. There may be other factors that influence university startup activity which are not included in the study. Indeed, it is likely that there is unobserved heterogeneity among the universities, but this study goes beyond most previous studies in its use of university-specific explanatory variables in the estimation.

For the full sample, land-grant status, *ceteris paribus,* generally implies 0.39 fewer startups initiated, and 0.30 fewer operational startups per university per year. Similarly, private status generally implies 0.55 fewer startups initiated, and 0.47 fewer operational startups, per university per year. When the UC system is omitted, however, land-grant status implies 3.92 fewer annual operational startups per university,   and private status implies   5.7 fewer annual operational startups per university. Similarly, for the sample of universities with newer TTOs, land-grant status implies 3.01 fewer annual operational startups, and private status implies 5.12 fewer annual operational startups. As previously noted, land-grant institutions seem to generate research which is closer to commercial application (and so easier to license to existing firms), whereas private universities often lack a culture encouraging startups. Moreover, these effects seem most pronounced among universities that are relatively new to the technology transfer process.

The results for faculty size indicate that the required increase in a university's life science faculty for one additional annual startup is 167 faculty members in the full sample, or 67 percent of the sample mean. An increase in life science faculty has a significant effect on operational startups only for the sample of universities with older TTOs, and in this case the increase required for one more operational startup is 500, roughly doubling the sample mean. The results are somewhat less daunting for engineering faculty, at least for universities with older TTOs, in which case the required increase in faculty size is 71 for one more startup and 166 for one more operational startup, or 55 and 127 percent of the sample mean.

An increase in the quality of the science faculty has essentially no significant effect on the number of startups initiated, and one more operational startup per university in the full sample requires an increase in the NRC ranking of 4.25 (recall the scale only runs from one to five). That is, an increase of one in the life science faculty quality ranking of a university results in one more operational startup every four years. However, for those universities with newer TTOs, the required increase in the NRC ranking of the life science faculty to induce one more operational startup per university per year is only 0.23.

Increases in the quality of the engineering faculty generally have a significant effect on the number of startups initiated and operational. An increase in the NRC ranking of about one is required for an additional annual startup initiated per university in both the full sample and that without the UC system. However, the required increase in NRC ranking needed for the sample of universities with older TTOs is only 0.48, while that for those universities with newer TTOs is four. The results for cumulative operational startups per year are remarkable. Although the increase in NRC ranking required for one more operation startup for each university in the full sample is 3.2, it is only 0.25 in the sample when the UC system is omitted. This shows dramatically how the size of the UC system influences the results of this analysis.

The size of the TTO has no effect on startups initiated or operational, but the age of the TTO has some effect. Most noteworthy is the result that the increase in TTO age required for one more operational startup per university is only 5.6 years when the UC system is omitted, and only 3.1 years for those universities with newer TTOs. Mean TTO age is 12 and 9 years in these two samples.

The effects of changes in the annual number of invention disclosures are similar to those for TTO age. Additional disclosures do increase the number of startups initiated, but the number required to induce an additional startup initiated per university is generally quite large, ranging from 143 in the sample of universities with older TTOs, or 95 percent of the sample mean, to 208 in those universities with newer TTOs, or a four-fold increase of the sample mean. And the additional disclosures needed for one more operational startup per university per year for the full sample is 333, a five-fold increase of the sample mean. However, the increase in disclosures required for one more operational startup is only 23 when the UC system is omitted, and 15.6 for those universities with newer TTOs, or 38 and 31 percent of the relevant sample means.

Increases in external funding in the university and venture capital funding levels in the state have significant effects on startups, but these effects are not overwhelming. For example, in the full sample, an increase of one startup per university per year requires increases in federal funding of $273 million, industrial funding of $46 million, and venture capital funding of 14 billion. These amounts correspond to roughly a tripling of annual federal and industrial funding per university (the sample means are $95 million and $13 million), and a seven-fold increase in local venture capital funding (the sample mean is $1.7 billion). Similarly, in the full sample, an increase of one operational startup per university per year requires even larger increases in industrial funding of $76 million and venture capital funding of 32 billion.

Nevertheless, once again results differ dramatically for some subsamples of universities. Specifically, an increase of one operational startup per university per year requires an increase in industrial funding of only $5.6 million per university (46 percent of the sample mean) when the UC system is omitted, and only $7.2 million per university (59 percent of the sample mean) for those universities with newer TTOs. Moreover, an increase of one operational startup per university per year requires an increase in venture capital funding in the state of only $2.5 billion (roughly a 50 percent increase over the sample mean) when the UC system is omitted.

Finally, although changes in the NASDAQ index have no noticeable effect on the number of operational startups, as noted above, declines in the NASDAQ do indicate less attractive alternative investments, and therefore more startups initiated in some subsamples. Specifically, the annual decrease in the index required for an additional startup initiated per university is 250 points in the sample without the UC system, and 500 points in the sample of universities with newer TTOs. Both of these changes are, of course, large compared to the sample mean of about 18.

6. Conclusions

This study examines factors influencing entrepreneurship resulting from university research. The measures of entrepreneurship used were the annual number of startups initiated per university and the annual cumulative number of startups that remain operational per university. The primary results for startups initiated are that they are positively related to the quality of the engineering faculty, the levels of federal and industrial funding, the number of invention disclosures in the university, and the level of venture capital funding in the state, but negatively related to the land-grant and private status of the university. Interestingly, startups initiated are also negatively related to the change in the NASDAQ index both in the sample that omits the UC system and in the sample of universities with newer TTOs. An increase of one in the NRC ranking of a university's engineering faculty implies one more startup initiated each year. The increase in invention disclosures required for an additional startup is quite large, ranging from about 200 in the full sample 150 in the sample without the UC system. Although the changes in the levels of funding required to induce an additional startup are generally very large for the full sample, they are substantially smaller, and well within the realm of possibility, in the sample that omits the UC system and the sample of universities with newer TTOs. Finally, land-grant or private status generally implies one less startup every two years in the full sample. However, land-grant or private status implies roughly four fewer startups in the sample that omits the UC system and three fewer startups in the sample of universities with newer TTOs.

The number of cumulative operational (surviving) startups per university, on the other hand, is a better measure of the success of startups. The general results for operational startups are that they are positively related to the quality of the engineering faculty, the age of the TTO, the level of industrial funding, and the number of invention disclosures in the university, but negatively related to the land-grant and private status of the university. An unlikely increase of 3.2 in the NRC ranking of a university's engineering faculty is needed for one more operational startup per year in the full sample, but an increase of only 0.25 in the NRC ranking is needed for one more operational startup in sample when the UC system is omitted. Although the quality of the life science faculty does not seem to matter for startups initiated, and matters with limited significance for operational startups in the full sample, it is very important for operational startups in the sample of universities with newer TTOs. Specifically, an increase of only 0.23 in the NRC ranking of a university's life science faculty is needed for one more operational startup in this sample. The increase in invention disclosures required for one more operational startup is over 300 for the full sample, but only 23 in the sample without the UC system and about 16 in the sample of universities with newer TTOs. Again, the change in the level of industrial funding required for one more operational startup is very large for the full sample, though less large (roughly half of the sample mean) in the sample that omits the UC system and the sample of universities with newer TTOs. The results for a land-grant status and private status are essentially the same as those for startups initiated: about one less operational startup every two years in the full sample, but private (land-grant) status implies six (four) fewer operational startups in the sample that omits the UC system and five (three) fewer operational startups in the sample of universities with newer TTOs.

I examined a variety of alternative specifications of the general model to check the robustness of these results. I estimated these specifications with university fixed effects, but the number of observations was too small to allow meaningful results using both time and university fixed effects. I conducted all the tests using the current number of disclosures instead of the lagged value, and using lagged values of federal and industrial funding. I also estimated these specifications using nominal (instead of logged) values of the funding variables, so as not to omit those few observations with zero funding levels. The results were essentially the same in sign and significance.

Finally, perhaps the most important unanswered question about university startups involves the relationship between licenses made with startups and licenses made with established firms. There is evidence (Shane 2001, Lowe and Ziedonis 2004) that universities prefer to license to established firms, and then turn to startups as an inferior alternative. This study also provides evidence in support of this in the result that the presence of a medical school or land-grant status has a negative effect on startup activity. It is frequently argued that universities with medical schools or land-grant status tend to produce inventions that are closer to commercial application. If so, then these universities may be more likely to find established firms as licensees, and less likely to need startups. The unpublished working paper by Chukumba and Jensen (2005) makes an attempt to analyze this interrelationship, but this effort is limited in that the theory relies solely on differences in the costs of licensing to established firms versus startups, and the empirical analysis simply conducts separate reduced form estimations of licenses with established firms and licenses with startup firms. An analysis of the interaction between these two modes of licensing is essential to understanding university entrepreneurship.

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Table 1: Summary Statistics for Full Sample

Variable	Observations	Means	Standard Deviation	Minimum	Maximum
medschool	2747	0.49	0.50	0	1
landgrant	2004	0.32	0.46	0	1
private	2221	0.29	0.45	0	1
scisize	1858	247.71	326.84	9	3225
sciquality	1858	2.92	0.78	1.04	4.75
engsize	1308	101.75	87.00	7	423
engquality	1308	2.77	0.82	1.01	4.63
ttosize	2337	3.57	5.13	0	73
ttoage	2393	12.25	10.90	0	79
disclose	2473	64.47	86.94	0	973
fedfund (millions)	2418	95.3	144	0	2170
indfund (millions)	2379	13.1	20.4	0	318
ventcap (millions)	2459	1710	4590	0	43,200
nasdaq	2749	17.87	33.80	-41	84.30
startup	2054	1.96	3.06	0	31
cumstartup	983	13.64	21.58	0	206

Table 2: Negative Binomial Regressions for Startups Initiated

	full sample	without UC	older TTOs	newer TTOs
medschool	-0.001	-0.047	-0.191	-0.240**
	(0.077)	(0.079)	(0.146)	(0.102)
landgrant	-0.182***	-0.191***	-0.631***	-0.213***
	(0.067)	(0.068)	(0.150)	(0.085)
private	-0.271***	-0.274***	-0.013	-0.340***
	(0.083)	(0.085)	(0.159)	(0.107)
scisize	-3.04E-04**	-6.97E-05	-1.43E-04	-2.48E-05
	(1.33E-04)	(1.92E-04)	(1.76E-04)	(2.62E-04)
sciquality	-0.049	-0.382	-0.382	0.041
	(0.091)	(0.274)	(0.274)	(0.118)
engsize	0.000	0.000	0.004***	0.000
	(0.001)	(0.001)	(0.001)	(0.001)
engquality	0.440***	0.402***	0.532**	0.242**
	(0.090)	(0.094)	(0.220)	(0.114)
ttosize	0.004	0.019*	-0.009	0.022
	(0.008)	(0.011)	(0.007)	(0.016)
ttoage	0.005*	0.003	0.007	0.012
	(0.003)	(0.003)	(0.005)	(0.008)
lagdisclose	0.003***	0.003***	0.002***	0.005***
	(0.000)	(0.001)	(0.001)	(0.001)
lnfedfnd	0.163**	0.162**	0.025	0.154**
	(0.065)	(0.063)	(0.113)	(0.075)
lnindfnd	0.133***	0.125***	0.126***	0.151***
	(0.046)	(0.046)	(0.086)	(0.058)
lnventcap	0.057***	0.061***	0.130***	-0.010
	(0.021)	(0.021)	(0.031)	(0.025)
nasdaq	-9.21E-04	-1.87E-03**	-1.28E-03	-4.05E-03**
	(9.24E-04)	(7.4E-04)	(9.51E-04)	(1.63E-03)
N	778	769	181	597
pseudo R^2	0.182	0.166	0.234	0.144

Standard errors in parentheses: *p<0.10, **p<0.05; ***p<0.01

Table 3: Negative Binomial Regressions for Operational Startups

	full sample	without UC	older TTOs	newer TTOs
medschool	0.067	0.041	-0.070	-0.232**
	(0.100)	(0.095)	(0.199)	(0.112)
landgrant	-0.296***	-0.297***	-0.995***	-0.297***
	(0.087)	(0.082)	(0.161)	(0.098)
private	-0.470***	-0.2461***	-0.073	-0.564***
	(0.104)	(0.098)	(0.180)	(0.117)
scisize	-7.03E-05	181E-04	-1.68E-03***	1.73E-04
	(2.55E-04)	(2.51E-04)	(2.55E-04)	(3.27E-04)
sciquality	0.235**	0.167	-0.274	0.418***
	(0.121)	(0.116)	(0.213)	(0.138)
engsize	-3.02E-04	-5.77E-04	8.60E-03***	-1.37E-03*
	(7.65E-04)	(7.28E-04)	(1.62E-03)	(8.38E-04)
engquality	0.311***	0.293***	0.414*	0.121
	(0.118)	(0.111)	(0.245)	(0.126)
ttosize	0.001	0.022	0.002	0.030
	(0.017)	(0.017)	(0.027)	(0.022)
ttoage	0.015***	0.013***	0.003	0.031
	(0.004)	(0.003)	(0.009)	(0.010)
lagdisclose	0.003***	0.003***	0.001	0.006***
	(0.001)	(0.001)	(0.001)	(0.001)
lnfedfnd	0.066	0.058	0.522***	0.025
	(0.071)	(0.068)	(0.186)	(0.075)
lnindfnd	0.172***	0.162***	-0.241***	0.147***
	(0.058)	(0.055)	(0.118)	(0.062)
lnventcap	0.0523**	0.0494**	-0.013	0.008
	(0.023)	(0.022)	(0.043)	(0.028)
nasdaq	1.89E-03	1.62E-03	-8.51E-04	9.20E-04
	(1.38E-03)	(1.31E-03)	(2.01E-03)	(1.50E-03)
N	383	382	88	295
pseudo R^2	0.131	0.142	0.162	0.140

Standard errors in parentheses: *p<0.10, **p<0.05; ***p<0.01