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Synergies or Tradeoffs in University Life Sciences Research

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Abstract:

The Bayh-Dole Act of 1980, key court decisions, and several breakthrough process technologies, paved the way for a period of remarkable growth in the patenting of life science research by U.S. universities in the 1980s and 1990s. Using a multiple-output cost framework and panel data on 96 universities over two decades this article examines whether economies of scope and/or scale are present in university production of three major life science research outputs: journal articles, patents, and doctorates. The results show strong evidence of significant economies of scope between articles and patents and economies of scale in article and patent production, suggesting that larger universities have distinct cost advantages in the production of high quality research outputs.

Keywords: University patenting, life sciences, R&D, scale economies, scope economies, panel data

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Synergies or Tradeoffs in University Life Sciences Research

The Bayh-Dole Act of 1980, combined with three key court decisions[†] and several breakthrough process technologies,[‡] paved the way for a period of remarkable growth in the patenting of life science research by U.S. universities in the 1980s and 1990s.[§] During this time, the relative importance of life science patents granted to U.S. universities grew from 10% of all university patents in 1980 to almost 25% in 1999. This dramatic expansion in the role of life sciences research occurred in a period when overall university patents grew almost 10 fold from 340 patents granted in 1980 to 3274 in 1999.^{**} Likewise, funding to support research and education activities in the life sciences at major research universities nearly doubled in constant dollar terms, with an especially rapid expansion in the 1990s. Given recent patterns of investment activity in building and faculty hiring, U.S. research-oriented universities seem to anticipate life sciences will be one of, *if not the*, leading edge of knowledge and growth well into this new century.

Both the Bayh-Dole act and the ability to patent life forms have generated significant controversy over whether universities should be involved in patenting. While much of the debate has focused on ethical issues, from an economic standpoint the issue is whether having universities patent their life science inventions is a welfare increasing activity. One mechanism for welfare improvements might be internal to the university with patenting and any associated revenue streams helping to generate a virtuous cycle of

[†] The key court cases were *Diamond v. Chakrabarty* 1980, *Ex parte Allen* 1984, and *Ex-parte Hibberd* 1987.

[‡] For example, gene guns, computational capabilities, and micro-array technology.

[§] For the purposes of this research “life sciences” are defined as including biological and agricultural sciences including biotechnology, but excluding medicines, pharmaceuticals, and medical technologies (see section 2 and appendix for details).

^{**} These are authors’ calculations from US Patent office data available in Hall, Jaffe, and Trajtenberg.

higher quantity/quality research outcomes.^{††} A more common view in the literature seems to be that the increased focus on patenting within universities is likely to detract from both the quantity and quality of production of other key outputs.

Researchers concerned about university-level tradeoffs associated with the expansion of patenting tend to focus on three potential outcomes: 1) universities moving away from basic research to pursue commercial patents (Kennedy; Dasgupta and Ray; Blumenthal et al.); 2) universities placing priority on the establishment of intellectual property rights instead of on knowledge generation and idea sharing (Rai and Eisenberg, Campbell et al.); and 3) university research quality declining as patent activity increases (Henderson et al., Sampat et al.). All three of these tradeoffs can be translated into university research production outcomes, the first two into fewer and lower quality journal articles and potentially fewer doctorates, and the third into lower quality patents or articles (i.e., ones with fewer citations).

To date, most quantitative research on the impacts of academic patenting has focused on effects outside the university. Some important examples are the Jensen and Thursby (2001) examination of the private investment incentives associated with universities having the right to offer exclusive licensing of their patents, and the Zucker, Darby, and Brewer (1998) exploration of the synergy between top scientists and biotech firms where universities and companies are proximately located.^{‡‡} However, only with respect to the evolution of patent quality has there been any systematic empirical analysis done on the effects of increased patenting on university research performance, with the most recent evidence on patent citations suggesting no significant changes (Sampat et

^{††} Some examples of external mechanisms are discussed below.

^{‡‡} For other research on university patenting, see e.g., Foltz et al., Barham et al., Hall, Link, and Scott, Thursby and Thursby.

al.). Almost no empirical analysis has been done of the potential synergies or tradeoffs within the university between patents and other research outputs, specifically journal articles and completed doctorates. In addition to the potential for tradeoffs raised above, it is also easy to imagine scope economies emanating from high quality research that generates fertile articles and a rich pool of potential patent opportunities for enterprising technology transfer offices to exploit (Owen-Smith and Powell, 2003).

This article fills a large gap in this university patenting literature by examining whether economies of scope and/or scale are present in the production of three major life science research outputs: articles, patents, and doctorates. The methodological approach builds on Baumol, Panzar and Willig's (1988) framework by constructing a university multiple-output cost function as in de Groot, McMahon, and Volkwein (1991) and Cohn, Rhine, and Santos (1989). The multiple-output cost function is estimated using a random-effect panel data model for both quantity and quality-adjusted outputs. This dual formulation of analyzing research output avoids many of the strong assumptions needed to study cost complementarities in the primal - production function - form used in most patent analyses that build on the work of Hausman, Hall, and Griliches (1984). In particular, formulating a university objective function as cost minimization captures some of the key features of the underlying production technology without having to specify output prices or the maximization problem of administrators.^{§§}

The panel data econometrics advance previous cost-function estimations aimed at identifying the underlying properties of university production processes, as do the quality

^{§§} The common joke about university presidents is that the objective function they maximize has three arguments: a winning football team for the alumni, adequate parking for the faculty, and beer for the undergraduates. On a more serious vein, specifying the objective function of a university with respect to its multiple outputs and revenue sources, and its multiple levels of decentralized production units is a non-trivial undertaking.

adjustments made on output quantities. These empirical innovations are made possible by a dataset that combines annual data from 1981-1998 for 96 U.S. universities on life science research expenditures, patents, journal articles, and doctorates, including citation data for the patents and journal articles. The analysis starts with non-parametrically smoothed costs surfaces that provide visual evidence of scope and scale economies in the production of patents and articles, especially among universities with medium to large production levels. The econometric models then test for economies of scale and scope using a strict quantity measure and a quality-adjusted output measure as well as adjustments for autocorrelation in university research costs. The results show synergies rather than tradeoffs between patents and articles in the life sciences but not with doctorates. The results also demonstrate the fragility of pooled models relative to specifications that more fully utilize the panel structure of the data as well as the value, as suggested by Gertler and Waldman (1992), of taking quality into account when estimating multi-product cost functions.

The organization of the article is as follows. The next section explains the multi-product cost function estimation strategy and introduces the panel dataset on U.S. university life science research. The third section presents the results of the empirical analysis. The final section concludes.

2. Methods: Econometric Specification and the Panel Dataset

Standard analyses of patent production both in industry and at universities (e.g., Hausman, Hall, and Griliches) have used a production function approach to estimate the determinants of patent production. A recent piece by Graff, Rausser, and Small (2003)

has, following the work of Arora (1995), tested for complementarities in reduced form production function models among private firms. These techniques rest heavily on key assumptions regarding the nature of complementarities and the validity of some exclusion restrictions, which are unlikely to be satisfied in the typical university setting where output prices are difficult to measure.***

A more promising line of inquiry for identifying synergies or tradeoffs among multiple outputs involves using the dual, i.e. a cost-minimization framework, such as the approach developed by Baumol, Panzar, and Willig (1988). Since their work on scale and scope economies first appeared, this cost function approach has been applied extensively to many sectors including universities (e.g., de Groot, McMahon, and Volkwein, 1991; Cohn, Rhine, and Santos, 1989). These university applications of the Baumol, Panzar, and Willig framework involve either cross-sectional analyses, or pooled versions of panel data.

Typical multi-product cost function estimations are based on a version of the following equation,

$$(1) \quad C(\mathbf{Y}, \mathbf{w}) = a_o + \sum_j b_j Y_j + 1/2 \sum_j \sum_k c_{jk} Y_j Y_k + d\mathbf{w},$$

where $C(\mathbf{Y}, \mathbf{w})$ is the total cost of producing a vector of outputs \mathbf{Y} with a set of input prices \mathbf{w} , and a_o , b_j , c_{jk} , d as scalars. The coefficient estimates, b_j and c_{jk} , are then used as evidence for synergies and tradeoffs and as arguments in the construction of estimates for ray economies of scale and economies of scope using formulas presented below in the empirical section.

*** Arora (1995) identifies two methods for identifying complementarities in the error structure of a primal equation. The first requires that there be only two outputs, while the second requires that one have data on all variables directly affecting the decision variables.

In the case of university research output in the life sciences, the vector of outputs Y are measured by journal publications, patents, and doctorates, while the costs are measured by the total expenditures on life sciences research in a given year. To control for the presence of university specific effects in the error structure, the panel data are used to estimate a standard random-effects GLS model, such as the one presented in equation (2).

$$(2) \quad k_{it} = \mathbf{a} + x_{it}\mathbf{b} + u_{it}, \text{ where } u_{it} = \mathbf{n}_i + \mathbf{e}_{it},$$

where k_{it} are costs, x_{it} represent the independent variables (Y, \mathbf{w}) , \mathbf{n}_i is a university specific residual while \mathbf{e}_{it} is the "usual" residual which contains both a time specific element and a standard equation residual. A random effects specification is chosen to accommodate some key regressors that change infrequently and to include an indicator variable for land grant institutions, which have outreach missions that likely raise costs. As a result the estimations are done under the assumption that x_{it} and the random effects, \mathbf{n}_i , are uncorrelated.

The structure of the university research funding process is such that current research costs in life sciences are likely to be highly correlated with those of the previous period. This correlation of year-to-year costs would imply that estimating equation (2) above as a standard random-effects model would be inefficient. The correlation can be described by a AR(1) process with a university specific autocorrelation estimate. If \mathbf{e}_{it} is produced by an AR(1) process, $\mathbf{e}_{it} = \mathbf{r}_i\mathbf{e}_{it-1} + \mathbf{h}_{it}$, then first differencing the model would give:

$$(3) \quad k_{it} - \mathbf{r}_i k_{it-1} = \mathbf{a}(1 - \mathbf{r}_i) + \mathbf{b}'(x_{it} - \mathbf{r}_i x_{it-1}) + \mathbf{h}_{it} + (1 - \mathbf{r}_i)\mathbf{n}_i,$$

where $\mathbf{h}_{it} = \mathbf{e}_{it} - \mathbf{r}_i \mathbf{e}_{it-1}$ (Hsiao, 1986).

In order to account for this autocorrelation, the estimation takes place in two stages: the first stage generates consistent estimates of the variance components $\hat{\mathbf{r}}_i$, $\hat{\mathbf{S}}_v^2$, and $\hat{\mathbf{S}}_h^2$ while the second performs a generalized least squares estimate of the model. A suitable estimation procedure for an AR(1) panel data model (Greene, Baltagi) can use one of many asymptotically equivalent estimators for the AR(1) process in the variance matrix, we use a regression of the residuals using lags. The GLS results are given by estimating (3) with the variance matrix transformed such that $\hat{\mathbf{b}}_{GLS} = (X' \hat{\mathbf{\Omega}}^{-1} X)^{-1} X' \hat{\mathbf{\Omega}}^{-1} k$ and $\hat{Var}(\hat{\mathbf{b}}_{GLS}) = (X' \hat{\mathbf{\Omega}}^{-1} X)^{-1}$. The matrix \mathbf{W} is defined as the Kronecker product: $\mathbf{W} = \mathbf{S}_{m \times m} \otimes \mathbf{I}_{T \times T}$, where for the T observations for unit i , the variance matrix will be $\hat{\mathbf{\Sigma}} = E[\mathbf{u}_i \mathbf{u}_i']$, where \mathbf{u}_{it} is now defined as $\mathbf{u}_{it} = (1 - \rho_i) \mathbf{n}_i + \rho_i \mathbf{u}_{it-1}$.

In terms of the functional form of the multiple-output cost framework, the literature presents a number of variants, including generalized quadratic and translog forms. Since some university-year combinations have zero patent outputs, the quadratic form is used in this paper. The econometric models estimated below include a pooled version of the data and random-effects panel data model with and without the AR(1) adjustment. The three econometric models are run using both strict quantity measures for research output and quality-adjusted quantity measures, where citations of articles and patents are used to control for quality of those two research outputs. The specifics of this quality adjustment are discussed in the data section.

Panel Data on University Life-Science Research, 1981-1998:

The dataset combines information on life science research inputs and outputs for 96 U.S. universities over an 18-year period, spanning an era of remarkable growth in the role of life sciences in universities and the global economy. We focus on the segment of life sciences - biological and agricultural sciences - that has been most affected by recent court rulings in the U.S. that allow patenting of life forms. These categories include biotechnologies but exclude non-biotech pharmaceuticals and medical applications, such as chemical processes, instrumentation, and devices. This choice is consistent with a historical division within most universities, where biological and agricultural life sciences are contained in distinct administrative units from medical and pharmaceutical schools. In addition, not all of the 96 universities have medical schools, and some medical schools would not have comparable biological and agricultural science units.

The 96 U.S. universities roughly correspond to the Carnegie classification of “Research I” universities,^{†††} and they are responsible for the vast majority of U.S. university production of articles and patents in life sciences. The exact choice was driven in large part by the availability of article data, but also by the availability of accurate cost data. Life science patent assignee and citation information were extracted from the NBER patent database (Hall, Jaffe, and Trajtenberg), while the Science Citation Index (ISI Web of Science) provided the life science article and citation counts by year for each university. Patents are credited by application year rather than by grant date in order to measure them as close as possible to the date research costs were involved. The data on the number of doctorates, university life science research costs, faculty salaries,

^{†††} “Research-I” universities is a category that was identified as a campus that in 1994 had at least \$40 million in federal R&D funding, while granting at least 50 doctorates per year. In 1994 there were 89 Research one universities, all but three of which are included in this data.

and other control variables discussed below were obtained from the National Science Foundation (NSF Webcaspar). A fuller description of the database, its sources, contents, and dimensions are provided in the appendix.

Quality measures for both articles and patents were constructed out of the citation counts.^{†††} Quality adjustments were sought because in the case of research output, quality is likely to matter significantly to the implicit value of the research and also to the potential synergies between patents and articles. In the first case, highly cited articles and patents are likely to generate flows of additional research or licensing funds to the author or assignee, while in the latter research that gives rise, for example, to an article that is highly cited may also be more likely to generate a patent than would a larger number of un-cited articles. Empirically, studies of patent citations have shown that they provide a reasonable proxy for both the quality of a patent and knowledge spillovers from patents, because each time a new patent uses a piece of research from another patent it is obligated to cite the previous patent (Henderson, Jaffe, and Trajtenberg, 1998). Article citations are also commonly used as measures of quality in studies of departmental or university quality (e.g. Adams).

Using citations as a quality measure requires attending to the time dependency of the counts, namely the truncation problem associated with more recent articles or patents that may not have had time to generate many citations (Sampat et al.). The quality measure constructed here for each life science article/patent is the deviation from the average citation rate of an article/patent in the same broad class/category published in the same year. For example, a 1995 biochemistry article with 10 citations is compared to the average level of citations of all biochemistry articles produced in that year. For a given

^{†††} We were unable to locate reliable data that could be used to quality adjust the doctorate data.

year, the average article has a citation rate of 1, with higher quality articles then having a measure greater than one and lower quality articles receiving a measure between zero and one. This relative citation approach minimizes a truncation bias that would be introduced by using an absolute citation count.

3. Empirical Results

3.1 Descriptive Statistics

A useful starting point for considering the issue of tradeoffs or synergies between university life science article, patent, and doctorate production is an aggregate view of the recent trends in those outputs. Table 1 demonstrates the tremendous takeoff in life science patent production at U.S. universities in the 1990s, with the number of accepted patents in 1998 at 16 times the level of 1981. Table 1 also shows the approximately 50% growth in published life sciences articles from 1981-1998 and the 33% growth in life science doctorates. The growth in life science article production shows steady growth over the entire period averaging about 2.4% per year, with the most rapid growth period being between 1984 and 1992. Patents show short growth spurts in the 1980's and then stable growth until 1995 when three years of exponential growth occurred. Doctorates, meanwhile, grew most in the early 1990s. While the boom in life science patenting in the late 1990s may have been fueled by the growth in life science article production in the earlier period, the leveling off of all three research outputs at much higher levels at the end of the 1990s suggests that at least strict tradeoffs among articles, doctorates, and patents during the boom era of life science patenting did **not** occur. It is possible,

nonetheless, that the explosion in patent activity in the latter part of the decade may have dampened the other forms of research production.

3.1.2 Cost Surfaces

While Table 1 demonstrates the growth of university life science outputs, it does not account for the increase in funding in the life sciences or give evidence on any potential complementarities between outputs. Descriptive evidence of economies of scale and scope can be seen in the realized cost surfaces of university production choices. A cost surface (or region) with cost complementarities will be convex with respect to costs across the two outputs, higher along the edges where more of a single product is produced and lower in the middle where both products are produced. A cost surface exhibiting returns to scale in a single product will be concave to the origin along one output axis.

Descriptive evidence on the shapes of university life sciences research cost surfaces is presented in Figures 2-4 using a non-parametric Lowess smoothing estimation procedure and the pooled dataset. Figure 2 shows the cost surface in article and doctorate quantity space, and demonstrates few if any complementarities, appearing weakly concave across the two outputs. However, with respect to articles in the middle of the article output space it does show some slight returns to scale for articles. The fairly uniform slope along the doctorates axis is suggestive of constant marginal costs of production for doctorates.

The relationship between articles and patents in quantity space is shown in Figure 3. With its strong concavity along the article axis, it demonstrates significant returns to

scale in article production, and with several convex regions in the article-patent plane it also appears to show cost complementarities. For example, one major convex region appears between 15 and 22 patents and 860 to 1280 articles. Also noteworthy is the plateau at the upper end of the article distribution, above 1,700 articles per year, where increases in either articles or patents appear relatively costless. This provides some suggestion that returns to scale and cost complementarities may exist for the most productive/largest universities.

The final non-parametric cost surface (Figure 4) depicts the quality-adjusted cost relationship between articles and patents. Along the article axis, the initial slope of this surface shows much steeper costs than did the quantity version, suggesting that quality research articles do not come cheaply. At higher levels of quality-adjusted article output, however, economies of scale do appear and persist. The cost surface also shows approximately the same inflection points for the major region of convexity between articles and patents, but overall this surface is less suggestive of cost complementarities than was the surface in quantity space. One striking feature of both quantity and quality curves for the article-patent space is that no universities are found in the upper quadrant defined by both high article and high patent production. Instead, the high article producers are moderate patent producers, and the high patent producers are moderate article producers.

Econometric Estimates:

Econometric estimations for the life science research cost function in terms of quantities and quality-adjusted outputs are presented in Tables 2 and 3. The pooled results are

shown in Table 2 and the random effects with and without the AR(1) specification are shown in Table 3. All three models are presented in both a quantity and quality adjusted version and have a balanced panel of 1,728 data points from 96 universities over 18 years (1981-1998). In addition to the quadratic formulation for the three research outputs, the remaining regressors are the average annual faculty salary for the university (a major labor input cost), an indicator variable for whether the university is a land grant (LGU) institution, and two indicator variables for the final two years in the data set.^{§§§} The land grant institution indicator is included to capture the additional extension and outreach mandates that these universities carry, which are presumed to involve higher costs per article, patent, or doctorate. In all of the regressions reported below, the three control variables, LGU and the two time indicators, are positive and significant.^{****}

While the pooled results are most comparable to previous university cost function estimations and the non-parametric surfaces discussed above, they appear to be the least robust of the alternative specifications. Most notable is the small and insignificant coefficient estimate on faculty salary, including a negative one in the quality-adjusted version, as compared to the much larger and significant positive coefficient estimates in the four random-effect specifications. Also, in the pooled quantity regression, doctorates appear costless to produce which is not the case in three of the other four random effects specifications. It is worth noting, nonetheless, that the coefficient estimates of the pooled models show rising and concave costs in articles and patents (scale economies) as well as

^{§§§} These indicators capture the fact that our accepted patent data end in 1999. Since it takes on average 2.5 years for a patent to be accepted, truncation of 1997 and 1998 data are likely.

^{****} The first estimate indicates that land grant institutions do indeed have higher life science research costs controlling for other outputs, while the two time -indicator estimates suggest that truncation effects on patent production for the last two years are worth controlling for in these cost function estimations.

weak evidence of synergies among patents and articles (a relatively large but insignificant coefficient estimate).

The random effects estimation results are shown in Tables 3. In general, these specifications provide more reasonable estimates of the faculty salary and doctorate parameters. They also exhibit significant cost complementarities between articles and patents but at the same time significant tradeoffs between doctorates and the other two research outputs. While overall levels of scope economies are explored below in the next section, the coefficient estimates in these regressions are consistent with scope economies among patents and articles but not between doctorates and other outputs. Also, in the random effects estimations, articles and patents are concave with respect to costs, and have cost parameters that are significantly different from each other. One troubling aspect of these random effects results is that the coefficient estimates on doctorates bounce around across the regressions, from negative and declining costs in the random effect quantity regression to positive and concave with respect to costs in the two AR(1) specifications.

In both versions, the AR(1) specification for the error term shows significant year to year correlation ($\mathbf{r}_i > 0.8$), with some changes in coefficient estimates and associated standard errors. These results suggest the presence of significant dynamics in the university production process that could warrant further attention. A careful comparison of the quality-adjusted random effects with and without the AR(1) adjustment, however, reveals highly similar coefficient estimates, with the main difference being whether doctorates are weakly concave or not in costs.

Overall, the above results across the various models provide strongly consistent evidence of cost complementarities between patents and articles, with negative and significant coefficients on the interaction term between the two. The other interaction terms demonstrate some tradeoffs between the other research outputs, i.e. between articles and doctorates and patents and doctorates, in all but the pooled models. Thus on an individual level, cost complementarities appear to be at work only for patents and articles but not across other research outputs.

Marginal Costs, Scope, and Scale Estimates

Using the estimated parameters from the quality-adjusted random effects model, Table 4 presents the marginal costs of life science patents, articles and doctorates. On average the estimated marginal cost of producing a life science journal article is \$43,000 while the marginal cost of producing a life science patent is an order of magnitude larger at \$482,000. The table shows the marginal cost of patenting declining over the period with the 1995 marginal cost only 72% of the 1981 cost. There are two technological changes in the life sciences during this period that are likely to be driving this trend: one is the dramatic improvements in the infrastructure (technology) of technology transfer at universities in the 1980's and 1990's, the other is improvements in research technology, including computational analyses, that have increased the speed of discovery. Since the marginal costs of article production should also be affected by improvements in research technologies, but in fact declined just over 10% in this same period, the changes in technology transfer capabilities might be the stronger effects. The rising marginal cost of producing doctorates seems to be driven by the tradeoffs between doctorates and both

article and patent production. That is, as article and particularly patent production rose over the two decades, doctorate production became increasingly costly.

In order to show both time and cross-sectional characteristics of the marginal cost estimates, graphs of the estimated marginal cost curves are presented in Figures 5-7. They show that both patents and articles have declining estimated marginal costs, while the marginal costs for doctorates are increasing. These curves are consistent with the results in Table 3 and suggest that the differences are more between time periods than they are across universities.

Evidence on ray economies of scale and scope can provide more global evidence on how the product by product cost complementarities and tradeoffs settle out at the university level. Using equation (1) above, one can define economies of scale and scope as follows:

1. *Ray Economies of Scale*: The ray economies of scale for the joint production process are defined by:

$$S_n(Y) = \frac{C(Y)}{\sum_j Y_j \frac{\partial C(Y)}{\partial Y_j}},$$

where ray economies of scale exist if $S_n(Y)$ is greater than one.

2. *Economies of Scope*: The economies of scope for a product set t relative to the product set of all other n products not including t : $(n-t)$, can be computed from following function:

$$SC_t(Y) = [C(Y_t) + C(Y_{n-t}) - C(Y)] / C(Y),$$

where $C(Y_t)$ is the cost of producing only the product set t and $C(Y_{n-t})$ is the cost of producing the other n products except those in set t . Economies of scope exist when $SC_t(Y) > 0$.

Estimates of economies of scale and scope using the coefficients from the random effects panel models for quantity and quality are presented in Table 5.

Despite coefficients suggesting economies of scale with respect to individual products, especially articles, in quantity terms life sciences research overall exhibits constant returns to scale. When adjusted for quality, however, the estimates show significant and economically meaningful returns to scale. Such increasing returns to scale in quality suggests major advantages for the leading universities and may pose a “barrier to entry” to small universities or those not currently heavily invested in the life sciences to producing quality articles, patents, and doctorates.

Economies of scope are evaluated comparing patenting as a separate operation from article and doctorate production with the joint production of all three. The scope estimate in quantity space is statistically indistinguishable from zero, and suggests few cost complementarities between patents and other outputs. In contrast when one takes into account the quality of research outputs the results show significant economies of scope. The economies of scope in quality space are suggestive of the idea that universities not only produce quality in both articles and patents but also do so at lower costs. This latter result demonstrates that while the regression results are fairly similar across the quantity and quality adjusted approaches, taking into account the quality of output has a significant effect on our understanding of the cost structure of life science research outputs at universities.

Conclusions:

This work has estimated cost functions for university life science research using panel data methods in order to investigate economies of scale and scope. In contrast to much of the literature on academic patenting, the dual formulation used here allows an explicit estimate of cost complementarities and obviates the need to specify prices for research outputs. The results demonstrate the benefits of using panel data to take into account time and university specific effects as well as the importance of taking into account quality in measuring university outputs.

In contrast to a literature that has worried about both the declining quality of university patenting and an increased commercialization of the academic enterprise due to patenting especially in the life sciences, the results show strong evidence of synergies between patents and other missions of research universities in the life sciences. Indeed, the evidence for economies of scope in quality-measured outputs suggests a possible virtuous cycle in which quality in articles and patents go hand in hand. Given that patents are a much more risky venture than articles in terms of their ability to generate income and that life science researchers have to generate enough income to maintain their labs, it is perhaps not that surprising that patents have not eclipsed articles as an output of choice. It may be that the strong incentives for steady income generation to pay the “rent” on lab space keep there from being tradeoffs between articles and patents. The strong economies of scale in university life science research suggest that larger universities may have a distinct cost advantage in the production of high quality outputs that, in turn, may mean that such a virtuous cycle is the province of only top universities.

This work has identified significant dynamics in the university production process, which deserve further modeling and empirical investigation. The aggregate level of these data could well be masking important micro-level dynamics, which in future research could be investigated at the individual scientist or lab level. In addition while this research was limited to major research universities, it is possible that even though synergies are evident at major research institutions, tradeoffs might dominate at lower level universities. Future research into university patenting could explore whether these synergies occur in other research areas and whether they can be more broadly achieved at universities that are not in the top tier of funding.

References:

- Adams, Amy. (1998). "Citation Analysis: Harvard Tops in Scientific Impact." *Science*. Vol. 281 (September 25): 1936.
- Arora, A. (1995). "Testing for Complementarities in Reduced Form Regressions: a Note." *Economic Letters*. 50: 51-55.
- Baltagi, Badi. 1995. *Econometric Analysis of Panel Data*. New York: John Wiley and sons publishing.
- Barham, B., J. D. Foltz, and K. Kim. (2002) "Trends in University Ag-Biotech Patent Production." *Review of Agricultural Economics*.
- Baumol, W., Panzar, J. and R. Willig. (1988). *Contestable Markets and the Theory of Industry Structure*. Revised Edition. San Diego: Harcourt Brace Jovanovich Press.
- Blumenthal, D., E. Campbell, N. Causino, K. S. Louis. (1996) "Participation of Life-Science Faculty in Research Relationships with Industry." *New England Journal of Medicine*. December 5, 1996. pp. 1734-1739.

- Campbell, E., B. Clarridge, M. Gokhale, L. Birenbaum, S. Hilgartner, N. Holtzman, and D. Blumenthal. (2002). "Data Withholding in Academic Genetics." *Journal of the American Medical Association*. January 23/30, Vol 287, No. 4, pp. 473 – 480.
- Cohn, E., S. Rhine, and M. Santos. (1989). "Institutions of Higher Education as Multi-Product Firms: Economies of Scale and Scope." *Review of Economics and Statistics*: 284-290.
- Dasgupta, P. and P.A. David. (1994). "Toward a New Economics of Science". *Research Policy*. pp:487-521.
- Foltz, J.D., K. Kim, and B. Barham. (2003) "A Dynamic Analysis of University Agricultural Biotechnology Patent Production." *American Journal of Agricultural Economics*.
- de Groot, H., W. McMahon, and J. F. Volkwein. (1991). "The Cost Structure of American Research Universities." *Review of Economics and Statistics*: 424-431.
- Gertler, P. J. and D. M. Waldman. (1992). "Quality Adjusted Cost Functions and Policy Evaluation in the Nursing Home Industry." *Journal of Political Economy*. Vol. 100, 6: 1232-1256.

- Graff, G., G. Rausser, and A. Small. (2003) "Agricultural Biotechnology's Complementary Intellectual Assets" *Review of Economics and Statistics*.
- Greene, W.H. *Econometric Analysis, 3rd Edition*. Upper Saddle River NJ: Prentice Hall, 1997.
- Hall, B., A. Jaffe, and M. Trajtenberg. (2003). "The NBER Patent Citation Data File: Lessons, Insights, and Methodological Tools." in A. Jaffe and M. Trajtenberg eds. *Patents, Citations, and Innovations: A Window on the Knowledge Economy*. Cambridge MA: MIT University Press.
- Hall, Bronwyn, Albert Link, and John Scott. (2000). "Universities as Research Partners". Typescript, University of California-Berkeley.
- Hausman, J., B. Hall, and Z. Griliches. "Economic Models for Count Data with an Application to the Patents-R&D Relationship." *Econometrica*. 52(1984):909-938.
- Henderson, R., A. Jaffe, and M. Trajtenberg. (1998). "University as a Source of Commercial Technology: A Detailed Analysis of University Patenting, 1965-1998." *Review of Economics and Statistics* 80(February): 119-27.
- Hsiao, Cheng. 1986. *Analysis of Panel Data*. Cambridge: Cambridge University Press.

ISI Web of Science. "Science Citation Index (SCI)". Thompson Scientific Publishing.

Accessed online at <http://isi0.isiknowledge.com/> (Last accessed May, 2002)

Jensen, R. and M. Thursby. (2001) "Proofs and Prototypes for Sale: The Licensing of University Inventions." *American Economic Review*, vol. 91, no. 1, March 2001, pp. 240-59

Judge, G., C. Hill, W. Griffiths, and T. Lee. 1985. *The Theory and Practice of Econometrics*. New York: John Wiley and Sons.

Kennedy, Donald. (2000) "Science and Secrecy." *Science*. Vol. 289 (August 4):724.

National Science Foundation. (2000). "NSF Webcaspar: Your Virtual Bookshelf of Statistics on Academic Science and Engineering."
<http://caspar.nsf.gov/>

Owen-Smith and Powell. (2003) "The Expanding Role of University Patenting in the Life Sciences: Assessing the Importance of Experience and Connectivity." Typescript. U. of Michigan.

Rai, Arti K. and Rebecca S. Eisenberg. (Forthcoming) "Bayh-Dole Reform and the Progress of Biomedicine" *Law and Contemporary Problems* Vol. 66 No. 1, 38 pages.

Sampat, B., D. Mowery, and A. Ziedonis (2003). "Changes in University Patent Quality after the Bayh-Dole Act: A Re-Examination." Typescript. Georgia Institute of Technology.

Thursby, J. and M. Thursby. (2000) "Who is Selling the Ivory Tower? Sources of Growth in University Licensing" *NBER Working Paper* No.7718, May 2000.

U. S. Patent Office. "Patent Bibliographic and Abstract Database."
<http://www.uspto.gov/patft/index.html>. (Last accessed July, 2002).

Zucker, L., M. Darby and M. Brewer. (1998) "Intellectual Human Capital and the Birth of U.S. Biotechnology Enterprises" *American Economic Review*, vol. 88, no. 1, March 1998, pp. 290-306.

Table 1
The Growth of University Life Science R&D: Patents, Articles, Doctorates

Year	Patents	Articles	Doctorates
1981	45	32,273	3,615
1982	57	33,498	3,638
1983	53	33,258	3,689
1984	54	34,201	3,842
1985	58	35,879	3,736
1986	74	36,402	3,701
1987	91	36,456	3,653
1988	93	38,067	3,870
1989	135	39,985	3,971
1990	129	41,291	4,101
1991	139	43,565	4,328
1992	186	45,624	4,439
1993	198	45,208	4,585
1994	246	46,482	4,677
1995	265	47,208	4,904
1996	398	47,269	5,120
1997	597	47,232	5,124
1998	757	48,342	5,143
Sample Average	199	40,680	4,230
Average Annual Growth Rate (%)			
1981-1998	19.4	2.4	2.1
1981-1990	13.6	2.8	1.5
1991-1998	25.9	2.0	2.9

Table 2
Life Science Cost Function: Pooled Regression
(Dependent variable: Life Science research costs)

	Quantity	Quality Adjusted
Patents	778.99 (399.15)*	698.28 (367.93)*
Articles	91.58 (6.51)***	56.55 (5.34)***
PhDs	-50.60 (63.33)	268.88 (59.74)***
Patents^2	-18.22 (17.46)	-12.07 (8.99)
Articles^2	-0.02 (0.01)***	-0.00 (0.00)*
PhDs^2	1.31 (1.17)	1.98 (0.83)**
Patent*Article	-1.15 (0.73)	-0.76 (0.34)**
Patent*PhDs	3.89 (8.06)	2.43 (5.37)
Article*PhDs	0.03 (0.17)	-0.28 (0.11)***
Faculty Salary	8.55 (42.81)	-28.48 (45.29)
LGU	13,295.55 (838.34)***	17,349.37 (922.02)***
yr97	4,236.33 (1,896.16)**	4,863.91 (2,066.82)**
yr98	6,047.70 (1,910.62)***	6,999.68 (2,097.01)***
Constant	-5,246.62 (2,382.30)**	-1,886.53 (2,548.94)
Observations	1728	1728
R-squared	0.76	0.73
Number of universities		

Robust standard errors in parentheses

* significant at 10%; ** significant at 5%; *** significant at 1%

Table 3
Life Science Cost Function: Panel Regression
(Dependent variable: Life Science research costs)

	Quantity		Quality Adjusted	
	Static Random Effects	Dynamic Random Effects (AR1)	Static Random Effects	Dynamic Random Effects (AR1)
Patents	658.02 (201.39)***	97.72 (112.54)	512.08 (183.21)***	177.15 (103.01)*
Articles	93.42 (5.81)***	75.27 (3.60)***	52.44 (3.80)***	35.23 (2.52)***
PhDs	-81.00 (43.95)*	27.65 (23.06)	46.67 (43.70)	127.14 (25.05)***
Patents^2	-20.56 (6.47)***	-0.04 (3.19)	-14.59 (3.83)***	-2.45 (1.88)
Articles^2	-0.04 (0.01)***	-0.02 (0.00)***	-0.01 (0.00)***	-0.01 (0.00)***
PhDs^2	-1.64 (0.60)***	-0.70 (0.31)**	0.52 (0.41)	-0.42 (0.23)*
Pat*Art	-1.02 (0.30)***	-0.49 (0.18)***	-0.50 (0.17)***	-0.37 (0.10)***
Pat*PhDs	9.01 (2.97)***	4.02 (1.69)**	5.35 (2.15)**	3.00 (1.26)**
Art*PhDs	0.53 (0.11)***	0.14 (0.06)**	0.08 (0.07)	0.08 (0.04)**
Faculty Salary	166.90 (37.49)***	359.28 (45.03)***	376.58 (36.66)***	418.58 (39.91)***
LGU	14,618.31 (2,799.67)***	17,872.73 (1,168.69)***	24,539.92 (2,942.59)***	30,041.66 (1,119.26)***
yr97	2,517.75 (855.66)***	1,467.07 (488.32)***	2,540.73 (901.35)***	1,669.45 (545.20)***
yr98	4,854.59 (911.09)***	2,717.22 (686.41)***	4,892.64 (944.65)***	3,342.35 (744.23)***
Constant	-14,435.88 (2,537.02)***	-20,113.48 (2,492.07)***	-18,643.07 (2,630.44)***	-17,879.98 (2,239.12)***
Observations	1728	1728	1728	1728
R-squared				
Number of universities	96	96 mean estimate of $\rho_i=0.87$	96	96 mean estimate of $\rho_i=0.82$

Robust standard errors in parentheses

* significant at 10%; ** significant at 5%; *** significant at 1%

Table 4
Marginal Costs for Life Science Outputs (in \$1,000)

Year	Marginal Cost Patents	Marginal Cost Articles	Marginal Cost Doctorates
1981	524	46	113
1982	516	45	115
1983	522	46	115
1984	507	45	121
1985	504	45	119
1986	513	45	117
1987	497	45	119
1988	499	44	123
1989	488	44	127
1990	474	43	132
1991	476	43	136
1992	448	42	142
1993	452	42	145
1994	403	41	156
1995	379	40	165
1996	464	42	153
1997	472	42	151
1998	537	43	140
Sample Average	482	43	133

Marginal costs in \$1,000 and evaluated using quantity random effects estimates at actual data points then averaged across universities by year. The years 1997 and 1998 demonstrate truncation in the patent series which adds to the marginal costs of patents.

Table 5
Estimates of Scale and Scope in Patents

	Quantity	Quality
Scale	1.019	1.479***
Scope ⁺⁺	0.037	0.354***

⁺⁺ Scope defined as comparing patent production only and article/doctorate production to producing all 3

*** Non-linear Wald test significantly different from 1 for scale and 0 for scope at a 1% level

Figure 1:
Life Science Cost Fn: Articles and PhDs(1981—1998) — Quantity

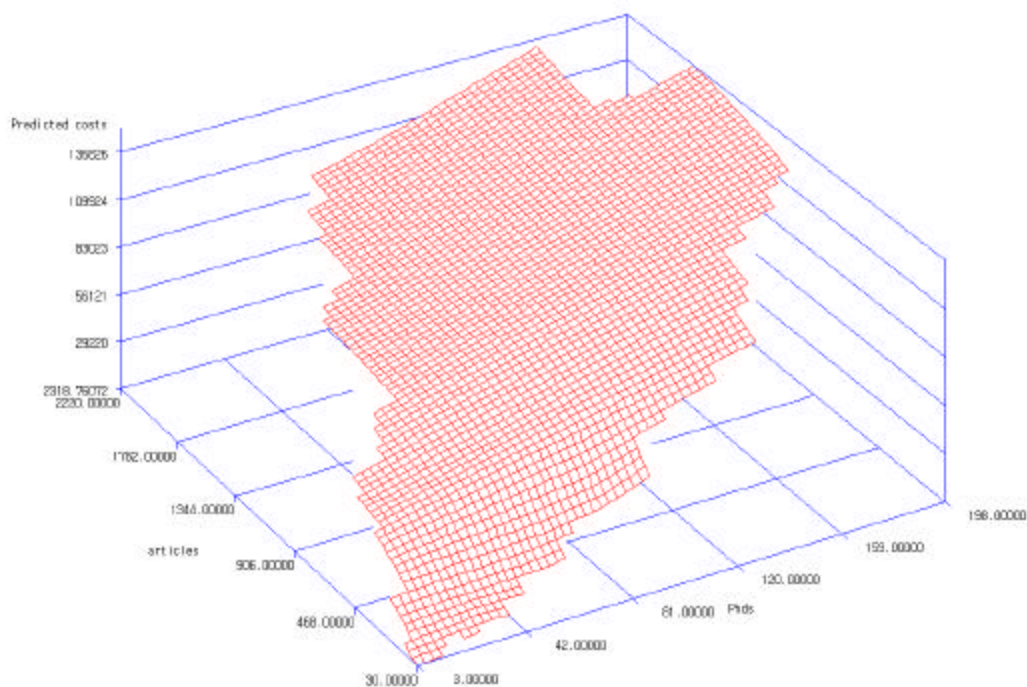


Figure 2:
Life Science Cost Fn: Articles and Patents(1981—1998) — Quantity

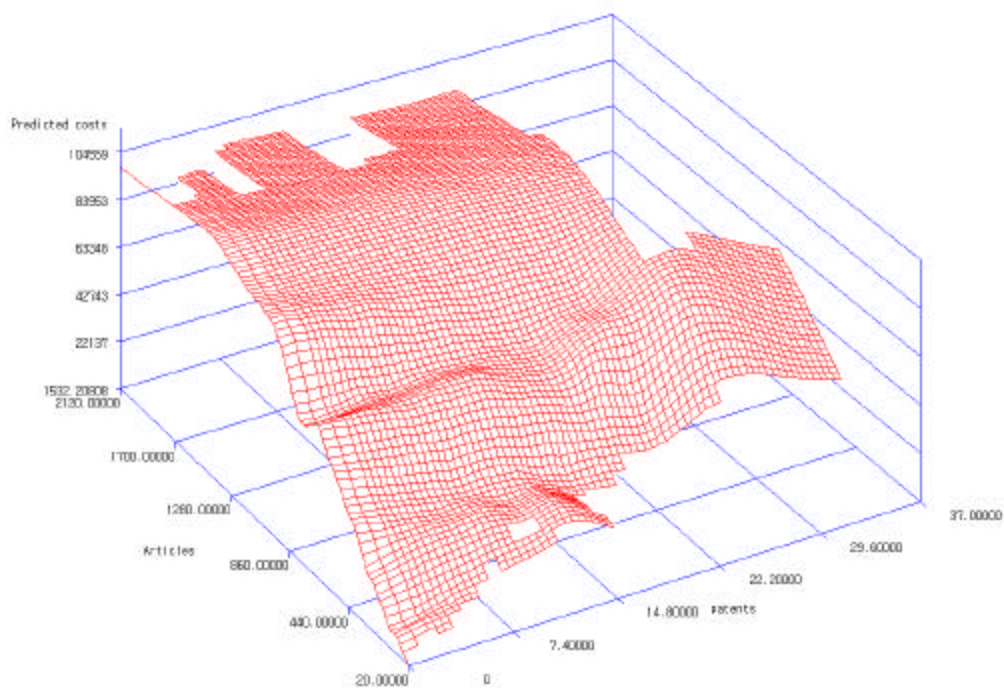


Figure 3:
 Life Science Cost Fn: Articles and Patents(1981—1998) — Quality

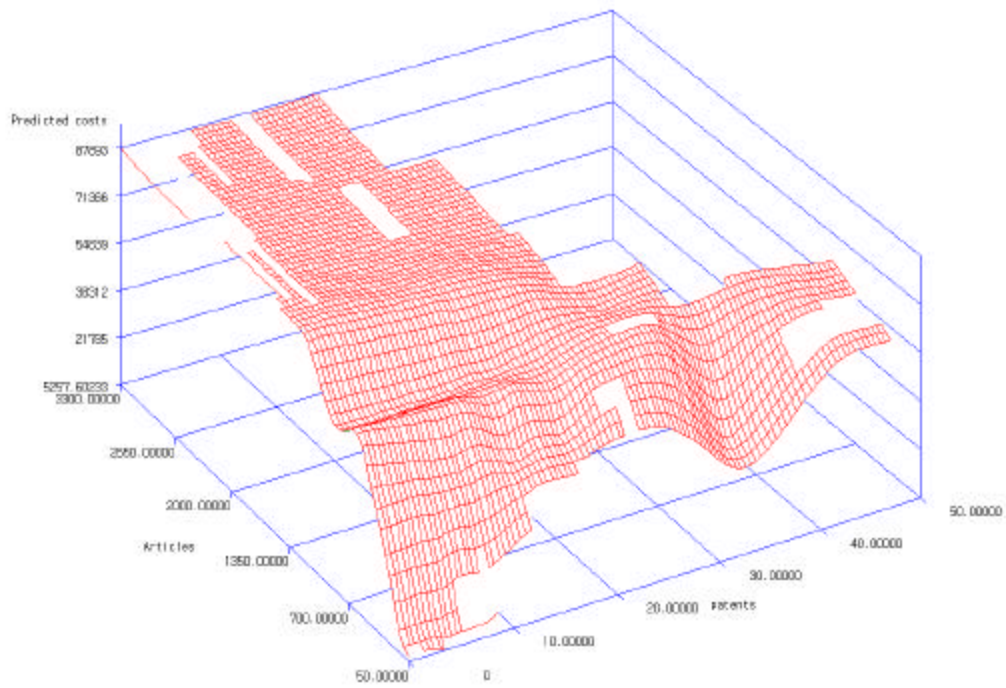


Figure 4:
Marginal Cost Curves for Patents

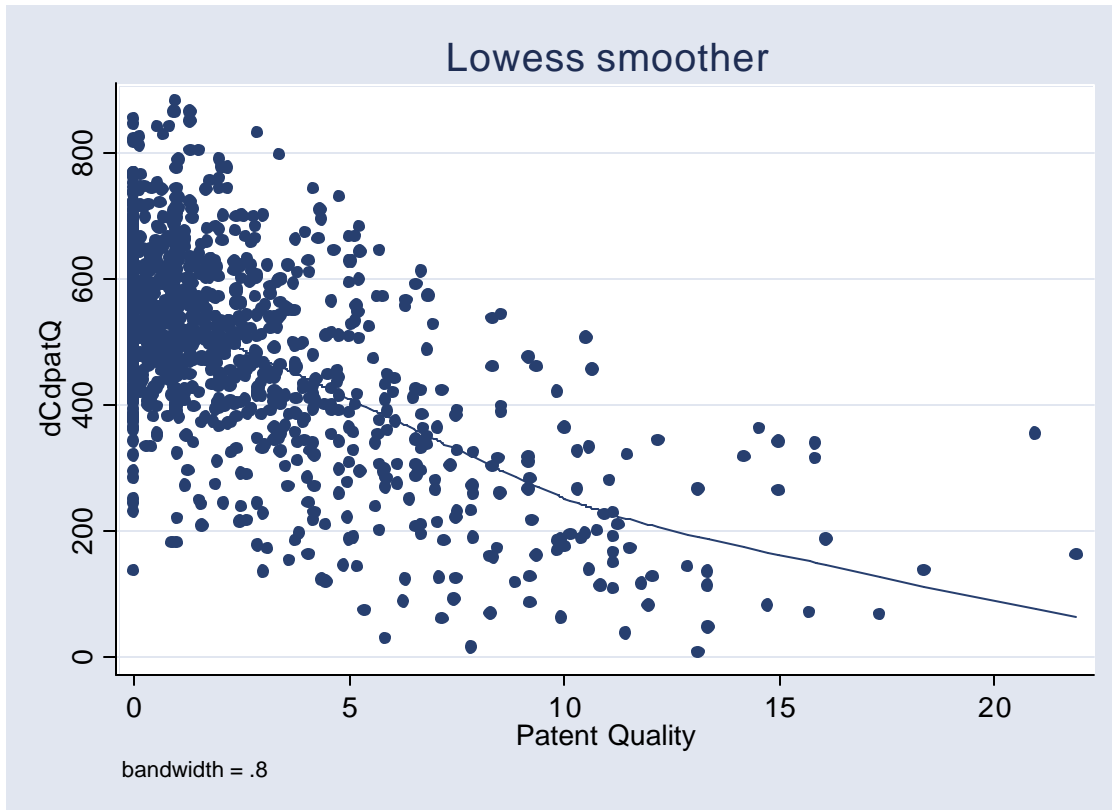


Figure 5:
Marginal Cost Curves for Articles

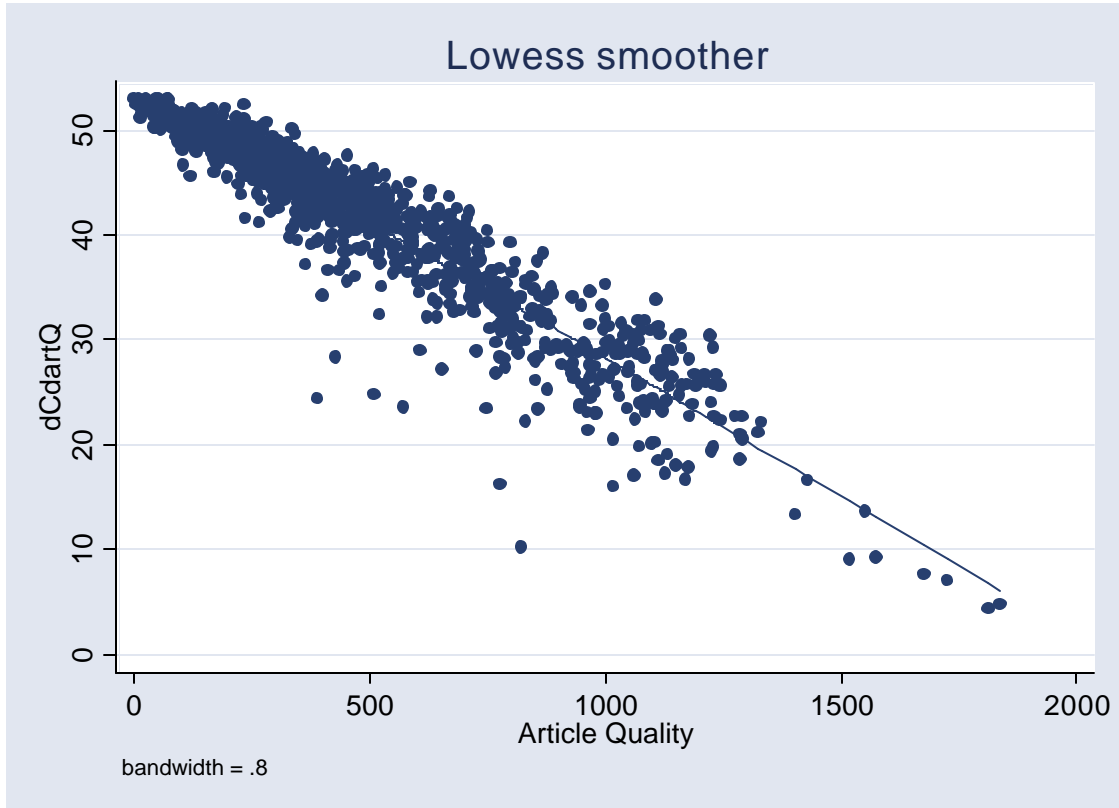
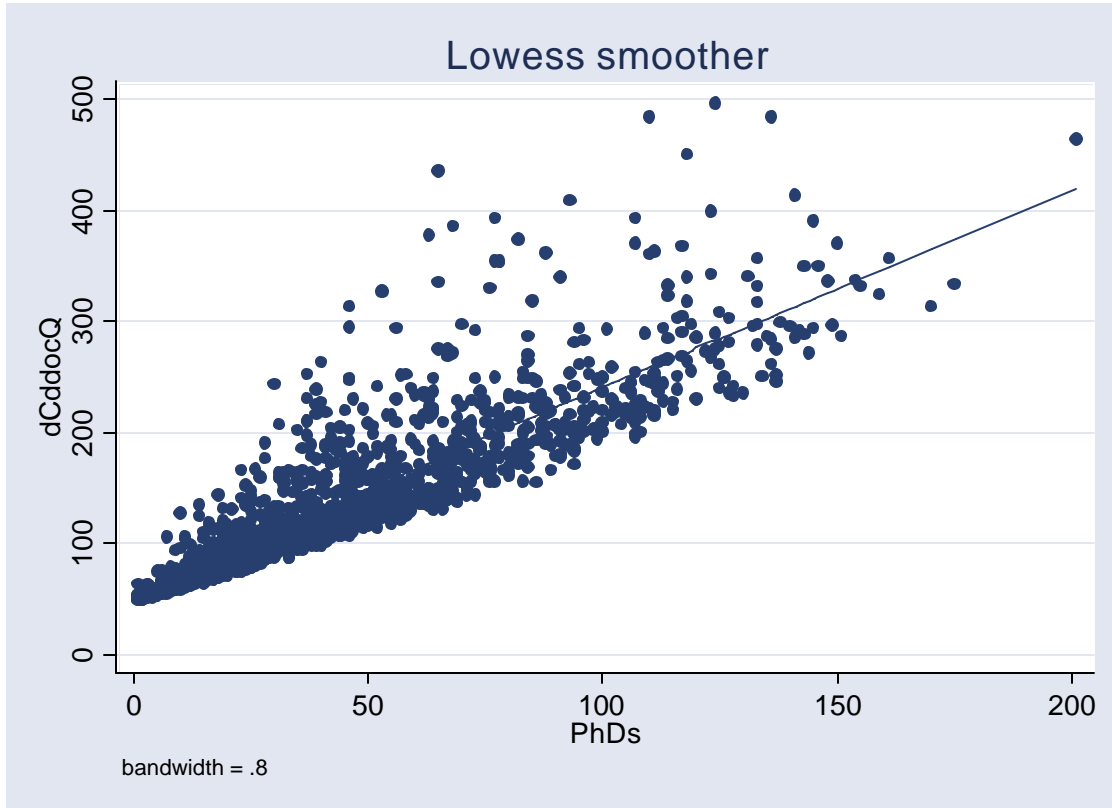


Figure 6:
Marginal Cost Curves for Doctorates



Data Appendix:

Patents

The patent data were culled from the NBER patent database, where they were identified as having a university assignee. Patents assigned to the University of California system were associated with a campus (Berkeley, Davis, Los Angeles, etc.) by the location of their authors through searches of campus directories.

Patents were categorized as life sciences based on the categories and sub-categories in Hall, Jaffe, Trajtenberg (pp. 452-453). Patents were chosen in the NBER sub-categories 33 (biotechnology as part of the drugs and medical category), 61 (agriculture, husbandry, and food as part of the “other” category), and 11 (Agriculture, food, and textiles, as a part of the chemical category). Within these subcategories, some US patent classes did not fit with a life sciences definition, mostly because they were classes that had agricultural, food processing, or textile machinery. Therefore, patents in 6 US patent classes (8, 19, 43, 99, 131, 442) were dropped. The resulting database includes patents in the following US Classes (47, 56, 71, 111, 119, 127, 426, 435, 449, 452, 460, 504, 800).

Relative citations for patents were generated by year comparing each individual patent to the universe of all patents (whether owned by universities or not) defined above as life sciences.

Articles

Article data were culled from the ISI-Web of Science database based on universities included in their “University Science Indicators” and categories established in that same document. The Web of Science includes only the major journals in a field as identified by impact factors, such that our article measures necessarily cut out articles written for lesser journals. In addition the citation measures are only for citations in other major journals. This truncation, we believe serves our purposes of adding a subtle quality measure even to our quantity measures.

The categories were chosen based on the journals that were included and the match of those journals with both the patent and funding data. They are: Agriculture, Biology & Biochemistry, Ecology/environment, Molecular Biology & Genetics, Microbiology, Multidisciplinary, Plant & Animal Sciences. While most of the categories are self explanatory, it is worth noting that the “Multidisciplinary” designation is used for major scientific journals such as *Science*, *Proceedings of the National Academy of Sciences*, and *Nature*. While this inevitably adds some noise to the data, we thought it better than “punishing” universities that regularly publish in the top journals.

Relative citations for articles were generated by category compared to citations of other articles assigned to the universities in the sample, rather than to all articles, and these measures were constructed annually.

Cost Data:

The cost data (life science research costs, faculty salaries) were culled from the NSF Webcaspar. All cost data were deflated using a GDP based deflator using 1996 as the base year. Life sciences combined NSF's categories of "biological sciences" and "agricultural sciences". These categories explicitly excluded medical sciences costs.

The faculty salary data were not collected in 1984, 1987, 1988, and 1989 and so were imputed for those years based on linear trends. The estimation results for the key parameters of interest were not sensitive to different methods of imputation of faculty salary for those years.