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Privatization of Agricultural Biotechnology Research in U.S. Universities

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Summary: The recent upsurge of privatization of university research, particularly in biotechnology, has attracted considerable attention. In the present study, we develop a structural model in knowledge production function framework to assess the impacts of university patenting and licensing on university research and on the downstream research which builds on university proprietary technologies to develop commercial agricultural biotech products.

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Overview of the Issues

Throughout most of the twentieth century, U.S. universities were inactive in patenting and licensing their research results, probably because of the perceived risk that such activities might harm their commitment to open science and the public good and injure their mission to generate and disseminate scientific knowledge. However, 1980 passage of Bayh-Dole Act (enabling universities to patent and license innovations resulting from federally-funded research) set up a uniform federal patent policy for academic institutions, and subsequent court decisions such as *Diamond vs. Chakrabarty* (allowing patents on living organisms) established patentability for more university inventions. Indeed, university patenting and licensing have increased dramatically since then.

The number of university technology transfer offices increased from 25 in 1980 to 200 in 1990, and by the end of the last century, such an office was operated at almost every U.S. research university to identify patentable inventions, market these inventions, and seek industry support for university research (Graff, Heiman, and Zilberman 2001; Nelson 2001). According to the AUTM Licensing Survey (Association of University Technology Managers, various years), fewer than 250 patents were annually issued to universities prior to 1980. But from 1985 through 2000, annual university patent awards rose from 550 to 3,272, while the share of university patents in total U.S. patents increased from 0.5% to 2.2%. Commercialization of university inventions has exhibited a similarly strong upward trend: in 2000, university licensing revenues amounted to \$1,263 million, up from \$186 million in 1991. Start-up companies founded on the basis of university research numbered 368, up from 223 in 1995.

As noted by Nelson (2001) and Zilberman, Yarkin, and Heiman (2001), the sharp increase in university patenting and licensing activities has concentrated in medical and biological fields. For example, biomedical inventions accounted for 75% of the inventions disclosed at Columbia University between 1980 and 1995 and for 75% of the patents licensed by the University of California from 1984 to 1990. Most of these biomedical inventions involved biotechnology in one way or another (Mowery et al 2001). In fact, the growth in university patenting and licensing may partly be an endogenous response to the biotechnological opportunities brought by the advances in modern molecular biology.

The recent upsurge of privatization of university research, particularly in biotechnology, has attracted considerable attention from the scientific community and university administrators as well as from government officials and the general public. It has stimulated one of the hottest debates on science and technology policy in the U.S. today. The controversy centers on the benefits and costs of increasing privatization of university research. The following dimensions are particularly important in that debate.

Proprietary vs. Open University Research

Supporters of the patenting trend argue that increasing university patenting and licensing activities facilitate commercial exploitation of university research, enhancing universities' contribution to local, national, and global economic growth. AUTM reports that over 2,000 products available to the public would not otherwise be available in the absence of university exclusive licensing activities. The licensing of university innovation in 1999 added more than \$40 billion to the U.S. economy and created 270,000 jobs.

On the other hand, others believe that U.S. universities' significant contribution to economic growth in the last century was mostly made possible by their commitment to open science, that is, to free dissemination of information in the public domain. Universities' and academic scientists' increasingly commercial interests have raised concerns about the culture and norms of university research and about the possibility of declining knowledge spillovers (positive externalities) from open science. Some complain that universities' increasing propensity to patent is impairing information flow from publications and professional conferences, and hindering informal scientific communication among mature scientists, graduate students, and post-doctoral researchers. Communication may be impaired not only between the university and industry sectors, but also among universities. For instance, university bioscientists have often reported that their inquiries about other academic scientists' research findings have been turned away, probably because of the latter's patenting hopes.

Because of Patent Office and court decisions in the 1980's to extend patentability to more fundamental research results, and because of the highly science-based nature of modern biotechnology, universities have patented many research-tool types of biotechnology findings, such as Cohen-Boyer's recombinant DNA framework and Cornell University's "gene gun" technique. Such a class of university inventions consists of important (in some cases necessary) tools or platforms for future research. Patenting of this class of "upstream" technologies may create difficulties in accessing needed IP for research purposes, and hence may reduce the diffusion of university inventions and dampen future innovation rates in biotechnology. A well-designed IP policy should balance the tension between providing incentives for innovation and allowing inventors to build upon one another's work.

Licensing Revenues vs. Costs

University technology transfer is recognized as a source of university revenue, an increasingly important factor as higher education faces budget cuts around the nation. Despite differences among universities in the schemes used for allocating such revenues between institution, research lab, and scientist, at least a substantial part of the revenue likely will serve as an input to future university research and education.

However, revenues come at a cost. First, the economic significance of university patenting is highly skewed; a very small proportion of the total awarded patents generate the majority of license income. It is believed that, at many universities, the costs to run the technology transfer office plus the legal fees for patenting outweigh the license revenues received. Second, the transaction costs of negotiating license agreements are a deadweight loss to society and likely increase with the usefulness and hence price of the licensed technology. Third, university licensing incomes translate into increases in the cost of using the patented research results, costs which ultimately must be borne by consumers.

University-Industry Relationships and the Potential Bias of University Research

Universities' patenting and licensing activities have brought a closer relationship between academia and industry, perhaps further enhancing universities' propensity to patent and license. University licensing to industry tends to bring in additional industry support for university research, often specified in the licensing agreement itself. Industry support ranges from R&D investment to proprietary information, genetic materials, and equipment. Indeed, some university research, either disseminated in the public domain or held as proprietary property, would have been impossible without access to genomic data or genetic materials held by

commercial firms. The knowledge gained from industry's downstream applications or development of the licensed upstream university technologies also feed back to universities more easily on account of the intimate research collaboration between the two sectors. Thus, patenting and licensing permits greater complementarity between university and industry R&D.

However, concerns have been expressed that rising industry funding for university research and the increasingly intimate relationship between university and firm may harm universities' image as an independent research entity, not to mention the credibility of university scientists themselves, especially in product trials which universities frequently conduct for industry. Some observers have worried that university-industry relationships may, in addition, shift academic research toward more applied questions, with a view to producing innovations that are easier to patent and transfer. U.S. universities have long been credited as the source of scientific breakthroughs which open new technological horizons. With universities' shift toward more applied research, present technological opportunities will be exhausted if the growth of our scientific knowledge base does not keep pace with the growth of its application and exploitation. Our national innovation system will lose its fuel in the long run.

All three dimensions discussed above interrelate with one another and together form the complex setting in which university agricultural biotechnology research operates. Most of the arguments presented above regarding the potential benefits or costs of increasing privatization of university research are based on isolated testimonials or on broad conceptual perceptions. They provide no idea about how large each benefit and cost might be at the national level. Furthermore, each argument tends to focus on only one dimension of this multi-dimensional subject. In the presence of interrelationships among all potential benefits and costs, the net effect

on innovation, productivity, and economic growth of the research privatization trend remain unclear.

Literature Review

Universities' "Open Science" Research and Its Impacts

Recognizing U.S. industry's heavy reliance on the basic science which traditionally has been disseminated in the public domain, economists have long been seeking to measure the economic contribution of universities' "open science" research. Many studies have been conducted to evaluate the returns to public agricultural R&D, employing university research and extension expenditures as shift terms in a production or cost function of a class of farm commodities (Griliches, 1958 and 1964; Huffman and Evenson, 1989; Pardey and Craig, 1989; Huffman and Evenson, 1993; Alston, Norton, and Pardey, 1995; Fuglie, et al., 1996). This approach permits direct inferences about the social welfare effects of public R&D expenditures, and probably was adequate for the time when agricultural research was concentrated in public institutions which publicly disseminated their research results. However, with increasing privatization of university research, other approaches are needed, allowing for detailed characterization of university publicly-disseminated and privately-owned research results and an explicit examination of their respective welfare effects.

Unfortunately, most economic studies on university research have not explicitly distinguished between public and proprietary research results, implicitly assuming that university research is open to everyone. For example, using surveys of major manufacturing firms, some economists have sought the scientific roots of commercialized products and processes (Nelson, 1986; Mansfield, 1991, 1995, 1998). Others have concentrated on university research

expenditures as an input to firms' innovation rates (Jaffe, 1989; Acs, Audretsch, and Feldman, 1992 and 1994), while still others have investigated the geographical approximation of private firms to leading university scientists, especially in biotechnology (Audretsch and Feldman, 1996; Audretsch and Stephan, 1996; Zucker, Darby, and Brewer, 1998; Zucker, Darby, and Armstrong, 2002). On the other hand, several studies have explicitly focused on university research disseminated through publicly accessible media such as publications. For example, employing a paper trail of information flows from agbiotech patent citations to universities' bioscience papers, Xia, Buccola, and Fare (2002) and Xia, Buccola and Fare (2004) found an unambiguously positive impact of university bioscience on agricultural biotechnological progress, and a corresponding complementarity between science and agricultural technology.

Universities' Patenting and Licensing and Their Impacts

With the recent upsurge of privatization of university research, investigators have begun analyzing the characteristics and production of proprietary technologies originating from university research. Using citation-based measures of importance and generality, Henderson, Jaffe, and Trajtenberg (1998) find that the proliferation since the mid-1980's in university patenting has been accompanied by a decrease in the average quality of university patents. In agricultural biotechnology, the number of university patents has risen exponentially in recent years (Buccola and Xia, 2004). These patented technologies consist of genetic transformation techniques, genes and gene traits, and germplasms. Although evidence suggests the quality of such patents has declined, some of the most important research-tool types of agbiotech patents are held by the university sector (Graff 2003). Foltz, Barham, and Kim (2000) and Foltz, Kim, and Barham (2003) examined the knowledge production of agbiotech patents in 100 U.S.

universities, concluding that the land grant infrastructure, the presence of “star” bioscientists, and previous patent success significantly affect a university’s agbiotech patent output.

Another line of research on university patenting and licensing is represented by the growing literature on the organization and efficiency of university technology transfer activities. Employing AUTM data (in conjunction with university technology transfer survey data in some cases), analysts have examined the relationship between a university’s financial, physical, human-capital, and organizational resources and the success of its technology transfers, usually measured by the number of licenses executed, the amount of licensing income received, and the amount of sponsored research (Siegel, Waldman, and Link, 1999; Thursby and Thursby, 2000; Thursby, Jensen, and Thursby, 2001; Thursby and Kemp; 2002; Powers; 2003; Friedman and Silberman; 2003). While these studies offer guidance to institutions engaged in commercialization efforts, they do not address whether universities are engaged too much in this effort from the social welfare perspective.

Although little quantitative work has emerged on this subject, some studies have started to tap into it in exploratory fashion. Among them are Mowery et al (2001), who exploit data at three leading universities and find that increasing patenting and licensing have little effect on the content of academic research. Such case studies, usually of top-ranked academic institutions, may provide in-depth insights but are not necessarily representative of the spectrum of U.S. research universities and hence are not adequate for drawing solid policy implications. In the present study, we develop a structural model in knowledge production function framework to assess the impacts of university patenting and licensing on university research and on the downstream research which builds on university proprietary technologies to develop commercial agbiotech products.

Conceptual Model

Three Types of University Patents

Economic welfare depends greatly on the flow of new products and services made available to the public. With that in mind, university patenting and licensing of biotechnological innovations can contribute to economic welfare in two ways: (1) by facilitating the utilization of university biotechnologies; and (2) by enhancing university revenues, which are invested in future university research. The first of these – patenting’s “usage” effect – arises both from the signal that the patenting process makes to potential commercial users and from the guarantee an exclusive license provides a firm that its competitors will not be allowed to commercialize the same technology. The second or “revenue” effect consists either of an upfront fee or profit-share royalty on the licensed use of the patented technology, or research grants or gifts to the university in the hope of future technology access.

University patents can be categorized into three types: (Type A) product patents, such as genetically modified germplasms; (Type B) specialized platform technologies, such as genes which activate particular immunities in certain types of fruit; and (Type C) broad platform technologies, such as the gene gun or the *agrobacterium* plasmid vector. Because technologies embodied in these three patent types differ fundamentally from one another, their patenting and licensing have quite different usage and revenue effects and consequently widely different welfare implications.

Type A or product patents embody the final step of the R&D process. Commercializing such patents usually requires a substantial investment in further field trials and marketing. Because they have a comparative disadvantage in marketing activities, universities normally cannot afford such investments. Commercial firms often are unwilling themselves to make the

investments without additional guarantees, since establishing a property right to the fruits of field trials and marketing is difficult. An exclusive license to a university's Type A patent likely is required to overcome this traditional free-rider problem and to induce the firm to bring the university's product innovations into the market place. Hence, usage effects are significant for Type A university patents.

The other two types of university patents, B and C, are farther still from commercialization. However, they can be used together with downstream R&D to generate more specialized platform technologies or marketable products. The winner in the downstream R&D race to employ such upstream technologies is entitled to establish intellectual property protection on the downstream inventions and hence to enjoy the monopoly profits derived from them. With patent Types B and C, then, patenting and exclusive licensing of university technology is unnecessary for solving the free-rider problem. The very patentability of the fruits of any downstream R&D that employs a university technology eliminates free riders.

An important difference does exist between the utilization of a Type B and a Type C university patent. Because a Type B patent is the more specialized of the two, any downstream research endeavor that a firm might base upon it would lead to an invention similar to that which any other firm might produce. The two firms' product innovations, that is, would be close demand substitutes for one another. Such competition implies that each firm's expected return to the downstream R&D investment on a given Type B university technology would be lower than the return it could achieve if the technology could be licensed exclusively. Consequently, no potential user of a Type B technology may end up using it. Patenting and exclusively licensing a Type B university technology likely therefore enhances its downstream usage by reducing the competitive pressure on downstream revenues.

In contrast, Type C university patents are broad; their potential applications are highly differentiable and often have low demand substitutability. Consequently, licensing a Type C university technology to one downstream user little affects the expected returns another user could achieve. Moreover, because Type C technologies are fundamental in nature, they will provide the framework for a wide area of downstream research whether or not they are patented. Hence, the patenting and licensing of a Type C university technology would have little usage effect.

Universities can earn revenues by licensing any type of patent. But proceeding along the continuum from a Type A to a Type C patent, technologies become increasingly upstream in nature and the research utilizing these technologies becomes increasingly patentable. In the limit, university research results are only publishable and no patent can be obtained. Patenting and licensing's usage effect, on the other hand, decreases, and the relative importance of the revenue effect rises, as one moves in the direction of a Type C patent. The farther upstream is a technology, the more significant is the reduction in knowledge flow when that technology is patented.

A Model of Knowledge Production

In a given time interval, let

Y be the number of agbiotech products a firm introduces to the market;
 Y_m^{univ} quantity of the m^{th} university research output type the biotech firm utilizes, where m ($m = 1, 2, 3, 4$) refers respectively to Type A, B, and C university patent and to university bioscience publications;

RD_{np}	amount of the p^{th} revenue type the university receives from a biotechnology firm utilizing the n^{th} university patent type, where p ($p = 1, 2$) refers respectively to royalties and research grants contingent on patent license agreement, and n ($n = 1, 2, 3$) refers respectively to Type A, B, and C university patent;
M_n	research materials and equipment the biotech firm provides the university, contingent on a license agreement to the n^{th} university patent type;
RD^{firm}	expenditures on R&D performed internally at the biotech firm;
RD^{univ}	university bioscience research expenditures derived from sources other than biotech firm royalties and research grants;
\mathbf{X}^{firm}	vector of the biotech firm's fixed factors;
\mathbf{X}^{univ}	vector of the university's fixed factors;
\mathbf{O}	vector of other factors impacting the quantity of marketable agricultural biotechnology products.

The number of marketable agbiotech product inventions, and the quantity of university research outputs contributing to those inventions, can be described by the firm's and university's knowledge production functions as follows:

Firm:

$$(1) \quad Y = Y(RD^{firm}, \mathbf{Y}^{univ}, \mathbf{X}^{firm}, \mathbf{O})$$

University:

$$(2) \quad \mathbf{Y}^{univ} = \mathbf{Y}^{univ}(RD^{univ}, \mathbf{RD}, \mathbf{M}, \mathbf{X}^{univ})$$

where \mathbf{Y}^{univ} , \mathbf{RD} , and \mathbf{M} are the vectors corresponding to Y_m^{univ} , RD_{np} , and M_n ($m = 1, 2, 3, 4$; $n = 1, 2, 3$; $p = 1, 2$). In equation (1), partial derivatives $\partial Y / \partial Y_m^{univ}$ ($m = 1, 2, 3, 4$) reflect the marginal effects of the four types of university research output – proprietary or in the public domain – on the number of agbiotech products eventually made available to the public. In equation (2), namely the university's multioutput knowledge production function, partial derivatives $\partial Y_m^{univ} / \partial RD_{np}$ reflect the marginal effects of licensing revenues on university research outputs. The latter effects likely differ by revenue type ($p = 1, 2$) because a university's financial support from sponsored research contracts usually is more restrictive than are a university's royalty incomes. They also likely differ by patent type ($n = 1, 2, 3$) because downstream development of university Type B patents usually requires more involvement of university inventors' efforts, so that sponsored research contingent on Type B patents usually is more specific and restrictive in topic area than is research contingent on Type A or Type C patents.

Substituting equation (2) into (1) gives the reduced form

$$(3) \quad Y = Y \left[RD^{firm}, \mathbf{Y}^{univ} \left(RD^{univ}, \mathbf{RD}, \mathbf{M}, \mathbf{X}^{univ} \right), \mathbf{X}^{firm}, \mathbf{O} \right]$$

Holding RD^{univ} , \mathbf{M} , \mathbf{X}^{univ} , \mathbf{X}^{firm} , and \mathbf{O} fixed, the total differential of (3) is

$$(4) \quad dY = \frac{\partial Y}{\partial RD^{firm}} dRD^{firm} + \sum_{m=1}^4 \sum_{n=1}^3 \sum_{p=1}^2 \frac{\partial Y}{\partial Y_m^{univ}} \frac{\partial Y_m^{univ}}{\partial RD_{np}} dRD_{np}.$$

Suppose the biotech firm faces budget constraint $RD^0 = RD^{firm} + \sum_{n=1}^3 \sum_{p=1}^2 RD_{np}$, implying

$$dRD^{firm} = - \sum_{n=1}^3 \sum_{p=1}^2 dRD_{np}. \text{ Substituting the latter into (4) and dividing by } \sum_{n=1}^3 \sum_{p=1}^2 dRD_{np} \text{ gives}$$

the total derivative

$$(5) \quad \frac{dY}{\sum_{n=1}^3 \sum_{p=1}^2 dRD_{np}} = -\frac{\partial Y}{\partial RD^{firm}} + \sum_{m=1}^4 \sum_{n=1}^3 \sum_{p=1}^2 \frac{\partial Y}{\partial Y_m^{univ}} \frac{\partial Y_m^{univ}}{\partial RD_{np}} \frac{dRD_{np}}{\sum_{n=1}^3 \sum_{p=1}^2 dRD_{np}}.$$

Each new dollar the university collects from a biotechnology firm utilizing its patented technology has two effects on the eventual quantity of marketed agbiotech products. These two effects are represented by the two right-hand terms of equation (5). First, observe that commercial firms' payments to universities reduce the money available for their own in-house research. The first right-hand term of (5) represents the direct (and negative) impact on the firm's output of such a reduction. The virtue of this extra dollar spent on university research – shown in the second right-hand term of (5) – is that it increases university research output. The amount of the increase, $\partial Y_m^{univ} / \partial RD_{np}$, depends on the allocation of the extra dollar across alternative patent types ($n = 1, 2, 3$) and revenue types ($p = 1, 2$). Such indirect effect feeds back into a higher rate of agbiotech product innovation and commercialization through the positive influence, $\partial Y / \partial Y_m^{univ}$, of university research output on the firm's agbiotech product development. When equation (5) is positive, university patenting and licensing enhance innovation and further the commercialization of agricultural biotechnology products.

Empirical Estimation

Data

To derive observations on \mathbf{Y}^{univ} , \mathbf{RD} , and \mathbf{M} , we conduct a survey of the agbiotech patenting and licensing activities of the technology transfer offices (TTOs) of major U.S. universities from 1985 to 2003. Surveys of university TTOs in earlier literature focus on characteristics of university inventions, objectives of university licensing, university intellectual

property policies, organizational practices and management of TTOs, and characteristics of license agreements (Siegel, Waldman, and Link, 1999; Jensen and Thursby, 2001). While they enhance our understanding of the “production process” of university patenting and licensing, these surveys do not link universities to downstream research or to the marketable products developed at biotech firms, nor do they recognize the three different types of university patents outlined and their differential usage and revenue effects. In our own survey of university TTOs, we seek, for each agbiotech patent a university licenses to biotech firms, specific information on patent number and title, the name of the licensee firm, the fee and royalty structure, the amount and restrictiveness of sponsored research, and the materials and equipment provided by the licensee. In doing so, we construct a paper trail of technology flow from university to firm.

Because university TTOs may not keep all such records, it may be simpler for them to provide copies of their license contracts. The option to answer our survey questionnaire or to provide copies of contracts should substantially boost our response rate (response rates to university TTO surveys has been around 50%). The survey is pretested on experienced technology transfer professionals and the survey design ambiguities identified and removed. University agbiotech patents which are not licensed are also identified from the agbiotech patent database developed in Xia (2002). It is important to count these non-licensed patents, especially of Type C, because they may involve negative usage effects. After collecting the patenting and licensing data, we develop a protocol for categorizing university patents into the three types discussed in the previous section. The fourth type of university research output, bioscience publications, can be measured by that university’s biotech-firm-cited scientific papers.

Annual data on R&D expenditures, stratified by academic discipline, are available from NSF’s WebCASPARE database. This database also reports number of faculty by academic rank

and faculty salary, number of postdoc researchers and graduate students, degrees awarded, and enrollment and tuition. Data on other university fixed factors, such as geographic location, Carnegie classifications, land-grant status, and graduate program ranking are provided by the U.S. Department of Education and the *Gourman Report*. Information on annual R&D expenditures at biotechnology firms is available from COMPUSTAT. At a modest on-line subscription cost, BioScan reports firms' locations, year founded, employment, sales volumes, and product focus.

Lag Structure

An important issue is the lag between a technology's invention and application. Inventions of a more applied nature tend to have shorter lags than do basic innovations, and the recently-patented inventions in our university sample may not yet have had sufficient time to be utilized. These issues can be addressed in empirical analysis.

Concluding Remarks

The present research will shed light on the social benefits and costs of the trend toward privatization of university research, with particular reference to exclusivity/openness tradeoffs, licensing revenue/cost issues, and the potential bias effects of university-industry relationships. Aggregating across, as well as distinguishing separately between, these three dimensions will provide policy makers with improved estimates of privatization's welfare effects and point the way toward any needed policy adjustments.

By recognizing the fundamental differences among the three principal types of agricultural biotechnology patents, and their differential usage and revenue effects on social welfare, this research will help guide university patenting and licensing practices. For example,

it will help indicate which types of technology a university would most be advised to patent if it wishes to maximize its access to the market place. It will also help suggest the revenue and payment structures universities might wish to institute for each type of technology in its research portfolio, including the use of up-front fees, sponsored research, material and equipment clauses. Overall, the research will provide the empirical analysis necessary for informing important policy choices in today's university environment.

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