UNTIL APPROXIMATELY THE BEGINNING of the twentieth century, colleges and universities were established primarily for instruction. Around the turn of the century, major U.S. colleges and universities were transformed into institutions that combined student instruction with discovery or knowledge creation through organized research (Goldin 2001; Huffman and Evenson 1993). This seemingly complementary organization of research and instruction in major U.S. universities is rather unique from a worldwide perspective. However, land-grant universities have taken an even broader mission of instruction, research, and dissemination of information beyond the university community (Huffman and Evenson 1993).

The political, economic, scientific, and legal environment in which universities operate has been evolving over the long term, but the pace of change seems to have quickened since the early 1980s. In particular, new scientific opportunities through rapid advances in biological sciences and information sciences, and changes in intellectual property right (IPR) policies have created new opportunities for universities. The U.S. Congress in 1980 passed the Bayh-Dole Act (PL 96-517) which gave a major boost to privatization of research in the public sector. The key provisions were that (i) a uniform patent policy was established for federally funded research, (ii) university-industry collaboration was encouraged, (iii) universities and/or for-profit grantees/contractors were permitted to retain title to inventions developed through federal funding, and (iv) the federal government retained a non-exclusive license to utilize the invention throughout the world (U.S. Congress 1984). This legislation cleared up any uncertainty about title to inventions, gave leadership to the inventors/scientists, and established a uniform IPR standard for all federally funded research (Coffman, Lesser, and McCouch 2003). In addition, the Diamond v. Chakrabarty Appeals Court Decision in 1980 expanded the set of discoveries that could be patented to microorganisms, and later in the 1980s patenting was extended to plants and animals.

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These changes strengthened the incentives for university applied research and were viewed as a way of enhancing the funding of universities, particularly in an era of declining public funding of universities. But these changes raise some important reservations about how university behavior might be altered as a result. Universities receive revenue from transfers (both public and private), including income from endowments and from direct sales of goods including instruction, applied research, and outreach. Traditionally, state and federal governments have been a major source of transfer revenue for public universities, but private universities were largely limited to federal government transfers such as research and education grants, private transfers in the form of donations, and tuition. With the Bayh-Dole Act, applied research that produces patents and basic research discoveries that can be protected as intellectual property have become a potential source of additional revenue. As different types of productivity are rewarded, it should not be surprising to see university activities shifted toward their most lucrative rewards.

This chapter examines not only conditions under which this intellectual property legislation increases universities’ willingness to partner with private industry to develop applied discoveries with patents and private market applications, but conditions under which such activities come at the cost of displacing the traditional instruction and basic research activities of universities. The former effect may displace research in the private sector that might otherwise be undertaken with private funds, but the latter effect reduces the supply of public goods such as freely disseminated basic research discoveries, the so-called “intellectual commons,” and education, all of which enhance future productivity in ways that may not be available otherwise (see Nelson 2003). Private partnering may be changing the relative composition of university activities away from production of such public goods toward production of private goods and royalty-generating activities, but, in some conditions, the additional funding opportunities may actually induce universities to reduce their absolute role in producing public goods, as possibly evidenced by higher tuition rates. Theoretical models that can be used as the basis for empirical analysis of these effects have been lacking.

The model of this chapter presents a framework that identifies key parameters that determine the qualitative nature of the expected reactions of major research-teaching universities to these changes in the legislative and scientific environment. Although in some universities each college or school operates relatively independently, collecting revenues and covering operating expenses (see Ehrenberg 2002, pp. 19–31), we abstract from the complex details of university decision making by modeling a university as a single enterprise that produces a mix of goods subject to resource constraints by maximizing a single-valued utility function reflecting the preferences of its chief

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1 While education may be regarded technically as a semi-public good because it generates both private and public returns, we use the term “public good” loosely here to encompass both pure public goods and semi-public goods in order to simplify discussion (see Cornes and Sandler 1996).
administrator(s) or other collective decision-making body. After deriving some basic results for the case where a university’s sources of funding are exogenous, we augment the model to consider the broader political economy of endogenous university funding. One result shows that the implications for displacement of traditional university activities are more dramatic when the university’s resource constraint is endogenous. Finally, we provide some empirical evidence from a panel data set of U.S. public and private universities, summarizing how revenue and expenditure patterns have changed since 1990. However, more work remains to test fully the conceptual model of university decision making.

Background

Major research universities have scientific expertise and knowledge that has been a key to commercial successes of new technologies in the areas of biotechnology, computer science, and materials science. Major developments have occurred in science that enable unusual manipulation of genetic materials as well as new information technologies and systems. The speed of DNA analysis has been greatly accelerated. Genomes for major farm animals and plants are almost completed. New techniques for successful interspecies gene transfers have advanced rapidly. Genetic engineering of cotton, soybeans, corn, canola, and some vegetable crops has been commercially successful. In the field crops, the early commercial applications of biotechnology have been associated with input use such as Bt-cotton, Bt-corn, and herbicide-tolerant soybeans. In the future, enhanced output traits hold further possibilities for enhancing the oil content of soybeans, the protein content of corn, the vitamin content of rice, etc.

These technical advances have been made possible by prior advances in basic science, for which follow-on discoveries are then embodied in materials or processes that are patented and sold commercially by the private sector. For example, in the United States, 72 percent of the papers cited in biotechnology patents have been by authors who are located solely in public institutions (McMillan, Narin, and Deeds 2000). Another 12 percent of citations have at least one author from a public institution. These statistics suggest that without successful transfer and dissemination of basic discoveries, the rate of technical advance would greatly dissipate. In addition, evidence of increasing linkages between U.S. technology and public science policy is accumulating (Narin, Hamilton, and Olivastro 1997).

As these advances have occurred, universities have been increasingly looking toward enhancing income by privatization of such discoveries. A few university offices of intellectual property (OIPs) were established during the early part of the last century – for example, at the University of Wisconsin (Wisconsin Alumni Research Foundation) about 1925, Iowa State University about 1935, and Kansas State University about 1942. But most were established after the Bayh-Dole Act (Massing 2000,
They came into existence to manage intellectual property for revenue generation or to build long-term relationships with private companies as patrons or partners (Abramson et al. 1997). Major activities of these offices now include locating, patenting, and licensing discoveries, enforcing property rights, and orchestrating “spin-off” inventions to start new companies. These institutions have facilitated the application, leasing, and enforcement of intellectual property rights from discoveries and inventions of its university faculty (and graduate students). Also, a common practice in universities is for the OIP to share net royalty income with the inventors or discoverers.

The Bayh-Dole Act has been a major force behind increases in university patenting, licensing income, and technology transfer efforts related to start-up companies (see Massing 2000; Henderson, Jaffe, and Trajtenberg 1998; Jaffe 2000, p. 542; Parker, Castillo, and Zilberman 2000). Data on patenting activity show an increase from less than 400 patents per year awarded to U.S. universities before 1978 to about 1,100 per year by 1989, with a rapid increase through the 1990s to more than 3,000 by 1999 (Massing 2000). (A slight downturn has occurred as information and computer technology has hit hard times in the economic recession of the early twenty-first century.) Although university patenting had a positive trend that started long before the Bayh-Dole Act, the new Act apparently provided a major incentive for universities to shift their research funding sources and activity toward discoveries more likely to yield revenue from selling or licensing patents and discoveries or from supporting start-up companies.

With this emphasis, the activities of these OIPs have focused on protection of IPRs from immediate disclosure of discoveries and inventions, which have led to limitations on disclosure, including limitations on publication of new results and restrictions on information sharing (see Coffman, Lesser, and McCouch 2003). Traditionally, university science has emphasized immediate disclosure of discoveries and innovations so that others in society can benefit from them more rapidly. In contrast, these new efforts to privatize and protect IPRs may undermine the collegiality of a university’s faculty and graduate students and, in the case of public institutions, may undermine the implicit contract that the university has with local taxpayers.

Technology transfer in the U.S. has built heavily upon the mobility of scientists, i.e., the process whereby university scientists and recent Ph.D.s and post-doctorates are hired temporarily or permanently by the private sector (Abramson et al. 1997). This method fits the traditional research and education mission of public universities well. With public-private sector partnering, private industry is primarily interested in using R&D for profit, e.g., using discovery and information in a strategic way to obtain a competitive edge. This means restricted exchange of scientific materials and information about discoveries, and delays in presentation of scientific results at professional meetings and in publication of research results. The publication of results
from Ph.D. dissertations may also be delayed, which can create conflicts with the university promotion and tenure process.

University OIP activity, including patenting for revenue, and technology assistance through business incubator programs (including university-industry-research centers, industry liaison programs, research consortia, and technology assistance programs) are outside the traditional mission of public universities. If or how these new methods can be molded over the long term into a successful multifaceted institutional university structure remains to be seen.

Traditionally, administrators of public universities have argued successfully that universities undertake public-good discoveries, that they contribute freely to the intellectual commons, that private provision of public goods leads to major under provision, and that therefore universities’ research budgets should be financed from public tax revenues. Much is unknown about the long-term effects of increased privatization of university research output and its implications for the reaction of taxpayers, the resulting public-private good mix of research output, the incentives faced by university scientists, and the social rate of return to public research. During the 1990s, U.S. federal funds for all research decreased at an average rate of 1.5 percent per year, and for agricultural research decreased at 1 percent per year. For all R&D and agricultural R&D, the private sector is the major source of funds, and its share has been growing. This trend may be viewed both as a cause and effect of the increasing privatization of university revenues. It also may be viewed both as a cause and effect of the rapid rise in tuition rates in recent times.

### A Theoretical Model of University Behavior

Universities are modeled as utility-maximizing institutions that have technology and resource constraints. We first lay out a dynamic model of university decisions considering the endogeneity of government transfers as influenced by past performance in a dynamic two-period model. While some basic insights can be gained in this general case, the model is too general for complete comparative dynamic analysis. To understand the basic implications of the model more fully, we then present a comparative static analysis of the second-period problem given choices in the first time period. We refer to this case as the static fixed-funding problem. We then consider long-run behavior in the dynamic model, which permits comparative static analysis of the endogenous funding problem.

Each university is assumed to make decisions as if it maximizes a (single) well-behaved neoclassical utility function in each time period reflecting the preferences of the university administration and the mission under which the university operates.
subject to a multi-period resource constraint.\textsuperscript{2} For example, the utility functions of private universities may differ from those of public universities and the utility functions of land-grant universities may differ from other public universities or those with other statutory funding.\textsuperscript{3} University preferences may also depend on the interests or expertise of faculty (under self-governance) and other local or university-specific factors. University utility is assumed to be determined by the quality-adjusted amounts of instruction, $x$, research discoveries associated with the development of private goods, $y$, and research discoveries associated with the development of public goods, $z$.

While the model has a parallel interpretation where $y$ and $z$ are distinguished as applied and basic research, respectively, a sharper interpretation is possible for studying the political economy of university funding with the definitions used here, given that some applied research serves to develop public goods and that some basic research results can be held as private goods depending on how they are disseminated. Thus, the private good research included in $y$ is research that develops goods for which the benefits can be appropriated in the marketplace through patents or other means. The public good research in $z$ is research associated with the development of public goods for which benefits either cannot be or are not appropriated in the marketplace but are rather disseminated freely to the general public through outreach activities or to the scientific community through academic journals and other professional media. While not all goods are purely public or purely private goods, we assume that all research outputs can be meaningfully proportioned between these two categories.

For notational purposes, university utility is represented by

$$u = u(x, y, z),$$

and $u'=u'(x', y', z')$ in the second and first time periods, respectively, where the dependence of preferences on university-specific factors is implicit and suppressed for convenience (primes distinguish variables in the first time period from those in the second throughout). The utility function is assumed to be increasing and weakly concave in $x$, $y$, and $z$, which implies $u_x > 0$, $u_y > 0$, $u_z > 0$, $u_{xx} \leq 0$, $u_{yy} \leq 0$, and $u_{zz} \leq 0$, and similarly for $u'$ where subscripts denote differentiation and the latter three inequalities become strict equalities under linearity of the utility function. We regard linearity of the utility function as an important benchmark case because we are aware

\textsuperscript{2} In reality, major universities operate under a system of governance that shares responsibilities among trustees (or boards of regents), administrators (e.g., the president and provost), the faculty and staff, and sometimes students. For tractability, however, this chapter must abstract from the theory of collective decision making.

\textsuperscript{3} The trustees or regents of public universities are responsible to the governor or state legislature whereas the trustees of private universities are responsible only to themselves (Ehrenberg 2002, pp. 19–31).
of no evidence to the contrary with respect to university behavior and because strict concavity is not necessary for optimization in the model below. In the event that linearity does not hold, concavity may reflect a preference to become a well-rounded “complete” institution of higher learning as size increases.

The university produces outputs $x$, $y$, and $z$ using inputs such as faculty, staff, and other labor of widely varying characteristics. A variety of other variable inputs are also required for the research and instruction functions. Additionally, universities possibly differ in their technology depending on facilities. All of these factors are assumed to be summarized in a university-specific cost function given by

$$c = c(x, y, z)$$

and $c' = c'(x', y', z')$ in the second and first time periods, respectively, where the dependence on university-specific faculty/staff and facility characteristics is implicit and suppressed for convenience. As usual, the cost function is assumed to be increasing and convex in $x$, $y$, and $z$, which implies $c_x > 0$, $c_y > 0$, $c_z > 0$, $c_{xx} > 0$, $c_{yy} > 0$, $c_{zz} > 0$, and similarly for $c'$. More specifically, we assume $c_{xy} < 0$, $c_{xz} < 0$, $c_{yz} < 0$, and similarly for $c'$ in order to capture the complementary nature of instruction and research and the enhancement of applied and private good research productivity that is believed to result from basic and public good research (see Just and Huffman, 1992, and Huffman and Evenson, 1993, for further discussion).

A university receives revenue from student tuition, royalties (implicitly including the sale of patents) on private good research discoveries, direct state and federal funding, grants, contracts for private good research, and private donations,

$$R = t + ry + g,$$  \hspace{1cm} (3)

where

$t =$ student tuition revenue,

$r =$ royalty rate per unit of private good research discoveries $y$,

$g =$ government transfers, grants, private contracts, and private donations.

Note that the utility and cost functions in the first period are not necessarily the same, respectively, as in the second period, even though they are assumed to satisfy the same qualitative properties. All prices and transfers are assumed to be expressed in real first-period prices.

In this chapter, we abstract from the style of university management labeled Responsibility Center Management. In this system, each college/school keeps all of the tuition from its students, overhead from grant funds received by its faculty, and college-specific donations, and then remits them to the central administration funds to cover the college’s designated share of central administration cost. Hence, each college is responsible for all of its direct and indirect costs. Under this management system, which fits most medical schools/colleges, the college faces incentives set by the upper administration to generate revenue and use these resources efficiently. The setting of a franchising fee, or designated

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Tuition revenue is determined by the tuition rate, \( t^* \), charged by the university and the number of students who choose to attend at that tuition rate. The number of students depends negatively on the tuition rate following the law of demand. Student demand is also influenced positively by university reputation, which we assume is determined by the amount of prior observable (publicly disseminated) research output (which may also proxy other measures of prestige such as Nobel prizes and National Academy memberships that tend to be positively correlated with public good research). Thus, student demand in the first time period is summarized by an implicit demand function, \( t' = t'(x', z') \), and the consequent university tuition revenue function is \( t' = t'(x', z') = x't'(x', z') \), where \( t' > 0 \) follows from \( t' > 0 \). In the typical public university case, where universities can raise tuition revenue by raising the tuition rate, student demand \( t' \) is inelastic, which implies \( t' < 0 \), but for public universities that charge higher tuition we assume that \( t' \) is higher \( \left( t' > 0 \right) \), with \( t' > 0 \) possible for a private university that pushes sufficiently toward product differentiation and monopoly pricing. The tuition revenue function is assumed to obey typical concavity assumptions, which implies \( t' < 0 \) and \( t' + t' = \left( t' \right)^2 > 0 \) in addition to \( t' < 0 \). In the second time period, we allow for a further impact of reputation through lagged observable (publicly disseminated) research output. Thus, the second-period tuition revenue function follows \( t = t(x, z') \), where \( t \) has qualitative properties parallel to those for \( t' \) (e.g., concavity with \( t' > 0 \), \( t' > 0 \), \( t' > 0 \), and \( t' < 0 \) for public universities).

Investigating the effect of 1980s science policy changes adequately requires modeling the political economy that determines the transfers in g. Congressional and legislative transfers to universities depend on public support and lobbying efforts on behalf of the university, which in turn depend on the university’s past actions. For example, at the federal level, if pork-barrel funding tends to attract a greater response of university private good research because of universities’ abilities to capture royalty income, then private industry can be expected to lobby Congress more vigorously in anticipation of sharing in the economic surplus from university discoveries. On the other hand, at the state level, producer and consumer groups may become less willing to lobby their state legislatures for university transfers if they go relatively more toward funding private good discoveries that mainly add to business and industry profits. Similarly, the general public can be expected to reduce their support for federal transfers that support public universities if the benefits are relatively more oriented toward research discoveries that result in monopoly pricing under patents with benefits that go primarily to producers and inventors and developers of the technology.
To add these considerations to the model, we assume that the university receives transfer income $g^x$ in the first period as determined exogenously by prior performance, while second-period transfers, $g = g^x + g^y + g^z$, are determined by first-period performance, where

$$g^x = \text{government transfers to support instruction plus private donations},$$
$$g^y = \text{government transfers and grants for private good research plus private sector contracts},$$
$$g^z = \text{government transfers and grants for research that develops public goods}.$$

Government transfers to support instruction in the second period are assumed to depend on the quality-adjusted level of university instruction provided in the first period, $g^x = g^x(x')$. For example, this dependence may include dependence of private donations on alumni numbers and their response to the quality of instruction as well as the political support for government funding.

Transfers and grants for private good research are influenced by business and industry lobbying efforts that affect legislative and congressional budget allocations. These are augmented by private contracts for research that enhance the profit-making potential of business and industry. Private contracts and lobbying depend on the reputation and track record of the university and its faculty. Thus, transfers for private good research in the second time period depend on private good research productivity and the extent to which university research in the first time period enhances private profit-making possibilities. We also consider the possibility that these transfers as well as the marginal effect of past productivity increase as the royalty rate increases, at least in a lagged sense, because a given level of government funding may induce a greater university response in private good research (as demonstrated clearly in the static model below). Government transfers and grants plus contracts with the private sector for private good development are thus represented by $g^y = g^y(y', r')$ where $g^y_{y', r'} > 0$.

In contrast, $g^z$ includes transfers due to public interest lobbying efforts that influence legislative and congressional budget allocations. This support is assumed distinct from business and industry support that occurs through the same legislative and congressional processes. Public support for a university is assumed to increase as the public perceives a greater output of research that benefits the general public, which may reflect in part the quality indicators that tend to be associated with publicly disseminated research (e.g., university outreach activities, popular news accounts of research discoveries, and measures of prestige such as Nobel prizes, National Academy memberships, and published university rankings). Because response to reputation is a lagged response, government transfers and grants for public good research in the second time period are assumed to depend on the public good research productivity of the university and its faculty in the first time period, $g^z = g^z(z')$. 
Each of these transfer functions is assumed to be increasing and weakly concave in their arguments. Although transfers typically come to universities with use restrictions, universities have considerable flexibility in using these funds because the use of tuition income is not restricted and because faculty effort is largely unobservable. Accordingly, we do not consider category-specific restrictions on the use of funds, although the utility function may weight various outputs differently depending on the operating and funding environment of the university.

In this framework, a university’s utility maximization problem may be represented as

\[
\max_{x', y', z'} L = u'(x', y', z') + u(x, y, z) \tag{4}
\]

subject to

\[
\pi' = r' y' - h'(x', y', z') = 0 \tag{5}
\]

\[
\pi = r y - h(x, y, z, x', y', z', r') = 0 \tag{6}
\]

where

\[
h'(x', y', z') = c'(x', y', z') - t'(x') - g', \]

\[
h(x, y, z, x', y', z', r') = c(x, y, z) - t(x, z') - g^{x}(x') - g^{y}(y', r') - g^{z}(z'). \tag{6}
\]

Based on assumptions above, \( h \) in (6) satisfies \( h_x = c_x - t_x > 0, h_y = c_y > 0, h_z = c_z - t_z > 0, h_{x'y'} = c_{x'y'} > 0, h_{zy'} = c_{zy'} - t_{zy'} > 0, h_{x'z'} = c_{x'z'} < 0, h_{zz'} = c_{zz'} < 0 \), and \( h_{x'y'} = c_{x'y'} - t_{x'y'} < 0 \), which implies \( h \) is increasing and convex in \( x, y, \) and \( z \).\(^7\) Also, \( h' \) in (5) has the same first- and second-order qualitative properties with respect to \( x', y' \), and \( z' \) as \( h \) has with respect to \( x, y, \) and \( z \). In addition, positive monotonicity and concavity of the tuition and transfer functions imply \( h_{x'} = -g^{x}_x < 0, h_{y'} = -g^{y}_y < 0, h_{z'} = -g^{z}_z < 0, h_{x'y'} = -g^{x'}_{x'y'} > 0, h_{zy'} = -t_{zy'} - g^{z'}_{zy'} > 0, h_{x'z'} = -t_{x'z'} < 0, \) and \( h_{z'} = -t_{z'} < 0 \), where all other cross derivatives are zero.

First-order conditions for the Lagrangian associated with (4)–(6), assuming an interior solution, are

---

\(^6\) Clearly we assume that a university behaves as one well-integrated unit and not as a set of fiefdoms organized around colleges/schools or distinguished professors.

\(^7\) The assumption \( c_t - t_c > 0 \) clearly holds for the case of a public university where \( t_c < 0 \), but it will also hold at the optimum for a public university with \( t_c > 0 \) because the positive marginal utility of instruction pushes production beyond the point where marginal cost is equal to marginal revenue. That is, the university is not viewed as a profit-maximizing institution.
\[ L_x = u_x - \lambda h_x = 0 \]  
\[ L_y = u_y + \lambda (r - h_y) = 0 \]  
\[ L_z = u_z - \lambda h_z = 0 \]

\[ L_\alpha = ry - h(x, y, z, x', y', z') = 0 \]  
\[ L_{\alpha'} = u_{\alpha'} + \lambda (r' - h_{\alpha'}) - \lambda' h_{\alpha'} = 0 \]

\[ L_{\gamma} = u_{\gamma} - \lambda h_{\gamma} = 0 \]

\[ L_{\gamma'} = u_{\gamma'} - \lambda h_{\gamma'} = 0 \]

\[ L_{\lambda'} = r'y' - h'(x', y', z') = 0 \]

where \( \lambda' \) and \( \lambda \) are Lagrangian multipliers for the first- and second-period budget constraints, respectively. Second-order conditions for this problem are too tedious to investigate directly although intuition based on the static fixed-funding model as well as the long-run model below suggests that second-order conditions are plausible if marginal transfers are bounded from above.

While complete comparative dynamic analysis of this model is not possible, conditions (7)–(14) add insight useful in its own right as well as understanding analysis of other models below. Rearranging equations (7) and (11) obtains

\[ u_x / \lambda = h_x = c_x - t_x, \]  
\[ u_x / \lambda' = h_{\alpha'} = c_{\alpha'} - t_{\alpha'} - \delta g_{\alpha'}, \]  

where \( \delta = \lambda / \lambda' \) reflects the real endogenous discount rate of the university, i.e., the marginal value of money in the second period relative to the first period. The left-hand sides of these equations represent money measures of the university’s marginal utility of increasing instruction in the second and first time periods, respectively (division by the Lagrangian multiplier converts utility to money terms). These are equated to the respective net marginal costs of increasing instruction. In the second period, the net marginal cost is the marginal cost minus the marginal tuition revenue, while in the first period this amount is augmented by the discounted marginal transfers in the second period due to the quality adjusted volume of instruction in the first period.

Similarly, rearranging equations (8) and (12) obtains

\[ u_y / \lambda = h_y - r = c_y - r, \]  
\[ u_y' / \lambda' = h_{\gamma'} - r' + \delta h_{\gamma'} = c_{\gamma'} - r' - \delta g_{\gamma'}. \]
These equations require equating the money measure of the marginal utility of private good research to the net marginal cost of increasing private good research in each time period. In the second period, the net marginal cost of private good research is the marginal cost of private good research less the marginal royalty income it generates (represented by $r$), while in the first period this amount is augmented by the discounted marginal transfers and private contracts in the second period that occur in response to private good research productivity in the first period.

Finally, rearranging equations (9) and (13) obtains

$$
\frac{u_z}{\lambda_z} = h_z = c_z - t_z, \quad (9')
$$

$$
\frac{u_z'}{\lambda_z'} = h'_z + \delta h_z = c'_z - t'_z + \delta (t_z + g_z). \quad (13')
$$

These relationships require equating the money measure of the marginal utility of public good research to the net marginal cost of increasing public good research in each time period. In the second period, the net marginal cost is the marginal cost of public good research less the marginal increase in tuition revenue it generates through the current reputation effect of student demand. In the first period, this amount is augmented by the discounted marginal tuition revenue as well as discounted marginal transfers for public good research, both generated in the future by the lagged reputation effect.

Of course, the remaining first-order conditions in (10) and (14) require simply that the budget constraints hold in each time period.

**Dynamic Analysis of the Bayh-Dole Act**

**One Approach to Investigate the Implications** of the Bayh-Dole Act in this dynamic setting is to assume that the pre-Bayh-Dole era can be usefully approximated by $r = 0$ whereas its enactment imposes a positive $r$. Dividing (7) by (8) and dividing (9) by (8) obtains

$$
\frac{u_x}{u_y} = \frac{c_x - t_x}{c_y - r}, \quad (15)
$$

$$
\frac{u_z}{u_y} = \frac{c_z - t_z}{c_y - r}. \quad (16)
$$

From (15) and (16), the intuitive implication of an increase in the royalty rate $r$ from zero caused by the Bayh-Dole Act is to reduce the denominators of both (15) and (16). Under the plausible assumption that the increase in $r$ is not sufficient to
more than offset all of the marginal cost of private good research, this calls for an
increase in the marginal rates of substitution on the left-hand sides of both (15) and
(16), i.e., substitution of private good research for instruction and public good
research. Accordingly, instruction and public good research tends to be cut back,
while private good research is increased. Only by an offsetting indirect effect of
increasing overall university revenues and the consequent reduction in the shadow
value of the university funding constraint can the indirect effects of adjustment
possibly increase instruction and public good research.

Turning to the first time period, equations corresponding to (15) and (16) are
derived by dividing (11) by (12) and (13) by (12),

\[
\frac{u'_i}{u'_j} = \frac{c'_i - t'_i - \delta g'_i}{c'_j - r' - \delta g'_j}, \quad (17)
\]

\[
\frac{u'_i}{u'_j} = \frac{c'_i - t'_i - \delta t'_i - \delta g'_i}{c'_j - r' - \delta g'_j}. \quad (18)
\]

These equations suggest results in the first time period similar to those in the second
time period because an increase in \( r' \) decreases both denominators and thus increases
the marginal rates of substitution on the left-hand sides. However, the results with
endogenous funding in (17) and (18) are likely to be more dramatic because \( r' \) has a
positive effect on \( g'_{ij} \), under the assumption that \( g'_{ij} > 0 \). Thus, the effect of adding
endogenous funding appears to further exacerbate the reduction of the denominator as
a direct effect of increasing \( r' \), which further adds to the substitution of private good
research for instruction and public good research.

Additional differences in the results for the first time period compared to the
second may be caused by the heavier incentives for first-period university activities
when they affect future transfers. These will tend to cause marginal rates of substitu-
tion to differ between the first and second periods and lead to indirect effects of ad-
justment that have intertemporal implications. For example, an increase in private
good research will increase the marginal effects of private good research on future
transfers as represented by \( g'_i \), which has a further negative effect on the denomin-
ators of (17) and (18), and thus adds to the substitution of private good research for
instruction and public good research. But this effect may be attenuated by the indirect
effects of endogenous adjustment related to instruction and public good research.
That is, the reduction in instruction and public good research will increase their re-
spective marginal effects on future transfers represented by \( g'_i \) and \( g'_j \), which has a
negative effect on the numerators of (17) and (18).
The net impact of all these indirect forces is thus not immediately clear. In an economy in which the business sector is atomistic and unorganized in lobbying efforts, the response of support for instruction and public good development may be greater. However, in a political economy that is heavily manipulated by private interests and rent seeking by a highly organized business sector, the mix of university output is likely to be pushed more toward research that develops private goods and away from public support of instruction and research that develops public goods. We suggest that the trend over time, particularly since 1980, has been toward the latter. (In fact, while we consider it exogenous for the purposes of this chapter, the very adoption of the Bayh-Dole Act may be an endogenous response to this growing business sector influence.)

A Static Fixed-Funding Model of University Behavior

Because comparative dynamic analysis of our full model of unified university operation is not fully tractable, the implications discussed above serve largely as conjectures that we investigate more carefully in the remainder of this chapter. For example, based on the discussion above, the effects of increasing the royalty rate appear to involve a displacement of traditional instruction and public good research activities with private good research, and the extent of that displacement appears to be greater when the endogeneity of university funding is considered. To investigate the first of these conjectures more carefully, we next analyze the second-period problem, taking decisions in the first period as given. That is, using the typical backwardation approach for dynamic problems, the first step is to analyze the second-period problem given decisions in the first period. Because past performance is fixed in the second period, the associated decision problem is one with fixed funding as far as government transfers are concerned, i.e., $g = g^i + g^p + g^r$ is fixed.

The university is thus assumed to choose the optimal output mix that maximizes its utility in (1) subject to the budget constraint that equates the cost function in (2) to the revenue in (3), i.e.,

$$\max_{x,y,z} L = u(x,y,z)$$

subject to

$$\pi = ry - h(x,y,z) = 0,$$

where

$$h(x,y,z) = c(x,y,z) - t(x,z) - g.$$
(10), another approach more suited to presentation of comparative static analysis is to solve the constraint in (20) for \( y \) to obtain \( y = y(x, z; r, g) \), and then substitute for \( y \) in the utility function. While such a \( y \) function cannot be derived explicitly, its properties can be derived implicitly. The university utility maximization problem can thus be considered as maximization of \( L = L(x, z; r, g) = u(x, y(x, z; r, g), z) \) with respect to \( x \) and \( z \) for which first-order conditions are

\[
L_x = u_x + u_y y_x = 0, \quad (21)
\]

\[
L_z = u_z + u_y y_z = 0. \quad (22)
\]

Equation (21) requires that the marginal utility from an additional unit of instruction must be equal to the marginal utility of private good research that must be given up according to the budget constraint to attain it. Equation (22) implies a similar relationship for the tradeoff between public good research and private good research. Because all marginal utilities are positive, these conditions imply \( y_x < 0 \) and \( y_z < 0 \). Note that equations (21) and (22) have implications identical to the first-order conditions in equations (7)–(10). In fact, equations (21) and (22) can be solved respectively to obtain \( u_x/u_y = -y_x \) in (15) and \( u_z/u_y = -y_z \) in (16).

Second-order conditions associated with (21) and (22) require that

\[
\frac{\partial^2}{\partial x^2} = u_{xx} + 2u_{xy} y_x + u_{yy} y_x^2 + u_{yxy} y_x < 0,
\]

\[
\frac{\partial^2}{\partial z^2} = u_{zz} + 2u_{zy} y_z + u_{yy} y_z^2 + u_{zyz} y_z < 0, \quad \text{and}
\]

\[
D \equiv L_{xx} L_{zz} - L_{xz}^2 > 0,
\]

where

\[
L_{xz} = u_{xz} + u_{yx} y_x + u_{zy} y_z + u_{yxy} y_x + u_{yzy} y_z + u_{yzy} y_z.
\quad (23)
\]

To examine the plausibility and implications of second-order conditions, note that comparative static analysis (total differentiation) of the budget constraint reveals \((\partial \pi/\partial y) dy + (\partial \pi/\partial x) dx = 0\) and similarly for total differentiation with respect to \( y \) and \( z \), which imply

\[
y_x = dy/dx = h_x/(r - h_y) < 0, \quad (24)
\]

\[
y_z = dy/dz = h_z/(r - h_y) < 0, \quad (25)
\]

where \( r - h_y < 0 \) follows from first-order conditions. Further differentiation of (24) and (25) reveals
where the signs of the first two expressions follow from convexity of \( h \) (positive definiteness of the Hessian of \( h \)) and the negativity of \( r - h_j \). With these results, the second-order condition \( L_{xx} < 0 \) is satisfied because \( u_{xx} + 2u_{xy}y_x + u_{yy}y_x^2 \leq 0 \) is implied by weak concavity of the utility function (negative semi-definiteness of the Hessian of \( u \)) because \( u_j > 0 \) and \( y_{xx} < 0 \) imply that the remaining term in \( L_{xx} \) is negative; \( L_{zz} < 0 \) is verified similarly. The positivity of \( D \) is somewhat more cumbersome to verify but also follows from the assumptions above.\(^8\)

A few special cases are useful for establishing results below.

**Lemma 1:** (a) If the complementarity of public good research and instruction is strong either in the cost function \( (c_{xz} << 0) \) or the tuition revenue function \( (t_{xz} >> 0) \), and the cost function is additively separable and linear in \( y \), \( c(x, y, z) = c_1(x, z) + c_2y \), then \( y_{xz} > 0 \). (b) If the complementarity of public good research and instruction is weak in both the cost function \( (c_{xz} \neq 0) \) and the tuition revenue function \( (t_{xz} \neq 0) \), and either the complementarity of private good research with teaching or public good research is strong in the cost function \( (c_{xy} << 0 \text{ or } c_{yz} << 0) \) or the returns to private good research are sufficiently diminishing \( (c_{xy} >> 0) \) or the returns to private good research are sufficiently diminishing \( (c_{xy} >> 0) \), then \( y_{xz} < 0 \).

**Proof:** Immediate from (26).

As an important reference point, we tie many of the results in this chapter to the assumption that the cost function is separable and linear in private good research. We regard this separability as a plausible approximation because private good research, which tends to be applied research, can more easily be accomplished by hiring additional research technicians and assistants to perform the more straightforward associated tasks than can instruction (except at the elementary levels) and public good research, which tends to be public good research. Because more straightforward activities tend to meet fewer barriers to expansion, we also regard linearity as a reasonable approximation. That is, expanding private good research activity does not meet severe

---

\(^8\) To briefly outline the proof that \( D > 0 \), let \( X = (1, y_x, 0) \) and \( Y = (0, y_z, 1) \), let \( H = \partial^2 u/\partial W \partial W' \) be the Hessian of \( u \) where \( W = (x, y, z) \), and let \( h = \partial^2 y/\partial w \partial w' \) be the Hessian of \( y \) where \( w = (x, z) \). Then \( D = |(X' Y' H (X' Y') + u_k k')|. The first term inside this determinant is a negative semidefinite matrix by weak concavity of the utility function and the second term is a negative definite matrix by concavity of \( y \). While the concavity of \( y \) is not shown explicitly above, the remaining requirement, \( y_{xx} y_{zz} - y_{xz}^2 > 0 \), can be shown by an approach similar to the first part of this footnote.
limitations in acquiring the necessary expertise to carry it out. By comparison, the expertise of high quality, creative, and difficult-to-acquire faculty required for basic research breakthroughs is a major limitation to the quality and quantity of basic public good research production at every university. In addition, this expertise is widely regarded as complementary with or even required for quality (advanced) instruction, particularly at the higher levels of education. For example, many universities that produce less basic research do not have Ph.D. programs.

**Lemma 2**: If utility is linear, then $L_{xz}$ is proportional to and has the same sign as $y_{xz}$. Also, $L_{xx}$ and $L_{zz}$ are proportional to and have the same signs as $y_{xx}$ and $y_{zz}$, respectively.

**Proof**: The first assertion is immediate from (23) and other assertions follow similarly.

While linear utility serves as an important reference point for the results below, the reader may bear in mind from (23) that $L_{xz}$ tends to be positive regardless of the sign of $y_{xz}$ as instruction and public good research become more complementary in university utility ($u_{xz} \gg 0$) and as private good research becomes a greater substitute with instruction or public good research in university utility ($u_{xy} << 0$ or $u_{yz} << 0$). Similarly, $L_{xz}$ tends to be negative regardless of the sign of $y_{xz}$ as instruction and public good research become greater substitutes in university utility ($u_{xz} << 0$), as private good research becomes more complementary with instruction or public good research in university utility ($u_{xy} >> 0$ or $u_{yz} >> 0$), and as the marginal utility of private good research diminishes more rapidly ($u_{yy} << 0$). Other nonlinearity in the utility function has no effect on the sign of $y_{xz}$.

**Implications of Increasing Royalty Returns on University Research**

The implications to the university of increasing the royalty rate for private good research can be examined by considering a change in $r$ in the model in (19) and (20). Specifically, consider the effects of a change in $r$ in the first-order conditions in equations (21) and (22),

\[
L_{xr} = u_{xy} y_x + u_{yx} y_y + u_{xyz} y_{xx} + u_{xzy} y_{yy} + u_{xyz} y_{yz}, \tag{27}
\]

\[
L_{zx} = u_{xz} y_x + u_{zx} y_x + u_{zxy} y_{xx} + u_{zx} y_{yy} + u_{zxy} y_{yz}. \tag{28}
\]

where comparative static analysis of the budget constraint, \((\partial \pi/\partial y)dy + (\partial \pi/\partial r)dr = 0\), reveals

\[
y_r = dy/dr = -y/(r - h_i) > 0. \tag{29}
\]
Equation (29) verifies the expected result that an increase in the royalty rate induces an increase in private good research.

Evaluating the implications of (27) and (28) requires the further derivatives
\[ y_{xr} = \left[ y_x h_{yx} + y_y h_{yy} y_x - y_x / (r - h_x) \right], \tag{30} \]
\[ y_{zr} = \left[ y_z h_{yz} + h_{yy} y_x y_z - y_z / (r - h_z) \right]. \tag{31} \]

**Lemma 3:** (a) If the complementarity of private good research and instruction is sufficiently strong in the cost function \((c_{xy} << 0)\) or the returns to private good research are sufficiently diminishing \((c_{yy} >> 0)\), then \(y_{xr} > 0\). (b) If the complementarity of public good and private good research is sufficiently strong in the cost function \((c_{yz} << 0)\) or the returns to private good research are sufficiently diminishing \((c_{yy} >> 0)\), then \(y_{zr} > 0\). (c) If the cost function is additively separable and linear in \(y\), then \(y_{xr} < 0\) and \(y_{zr} < 0\).

**Proof:** Immediate from (30) and (31).

**Lemma 4:** If utility is linear, then \(L_{xr}\) has the same sign as \(y_{xr}\), and \(L_{zr}\) has the same sign as \(y_{zr}\).

**Proof:** Immediate from (27) and (28).

Again, while linear utility serves as an important reference point for the results below, the reader may bear in mind from (27) and (29) that \(L_{xr}\) tends to be positive regardless of the sign of \(y_{xr}\) as instruction and private good research become more complementary in university utility \((u_{xy} >> 0)\) and as the marginal utility of private good research diminishes more rapidly \((u_{xy} << 0)\). Alternatively, \(L_{xr}\) tends to be negative regardless of the sign of \(y_{xr}\) as instruction and private good research become greater substitutes in university utility \((u_{xy} << 0)\). Other nonlinearity in the utility function has no effect. A similar statement applies from (28) and (29) for \(L_{zr}\).

For purposes of comparative static analysis of a change in the royalty rate, represent the first-order conditions in (21) and (22) compactly as \(L_w = 0\), where \(w = (x, z)\). Then total differentiation of the first-order conditions with respect to \(x, z,\) and \(r\) yields \(L_{wv} dw + L_{wr} dr = 0\), which implies \(dw/dr = -(L_{wv})^{-1} L_{wr}\). Application of Cramer’s rule to this problem reveals the individual equilibrium effects of a change in the royalty rate on university behavior,
\[ \frac{dx}{dr} = \left(1/D\right)(L_{xz} L_{zr} - L_{zx} L_{xr}), \tag{32} \]
\[ \frac{dz}{dr} = \left(1/D\right)(L_{zx} L_{xr} - L_{xx} L_{zr}). \tag{33} \]
**Proposition 1:** Suppose (i) the utility function is linear, (ii) the complementarity of public good research and instruction is strong either in the cost function \((c_{xz} << 0)\) or the tuition revenue function \((t_{xz} >> 0)\), and (iii) the cost function is additively separable and linear in private good research. Then an increase in the royalty rate on private good research causes both instruction and public good research to decline \((dx/dr < 0 \text{ and } dz/dr < 0)\).

**Proof:** Proposition 1 follows from the condition of Lemmas 2 and 4 as well as the conditions of Lemma 1(a), which in turn include the condition of Lemma 3(c).

**Proposition 2:** Suppose (i) the utility function is linear, (ii) the complementarity of public good research and instruction is weak in both the cost function \((c_{xz} = 0)\) and the tuition revenue function \((t_{xz} = 0)\), and (iii) private good research has constant returns to scale \((c_{yy} = 0)\). (a) If the complementarity of private good research and instruction is strong \((c_{xy} << 0)\) and the complementarity of public good and private good research is weak \((c_{yz} = 0)\), then an increase in the royalty rate on private good research causes instruction to increase \((dx/dr > 0)\). (b) If the complementarity of private good research and instruction is weak \((c_{xy} = 0)\) and the complementarity of public good and private good research is strong \((c_{yz} << 0)\), then an increase in the royalty rate on private good research causes public good research to increase \((dz/dr > 0)\).

While the results of Propositions 1 and 2 present some useful benchmarks, one can clearly find many other cases where increasing the royalty rate has determinate qualitative effects on instruction and public good research. For example, if instruction and public good research are complementary goods in university utility \((u_{xz} > 0)\), then the results of Proposition 1 are only strengthened compared to the linear utility case because this term has a positive effect in equation (23) while the other terms in (32) and (33) are unaffected. If private good research and instruction are complementary goods in university utility \((u_{xy} > 0)\), then the results of Proposition 2(a) are only strengthened compared to the linear utility case because this term has a positive effect in equation (27), a negative effect in equation (23), and does not affect other terms in equation (32). Similarly, if public good and private good research are complementary goods in university utility \((u_{yz} > 0)\), then the results of Proposition 2(b) are only strengthened compared to the linear utility case because this term has a positive effect in equation (28), a negative effect in equation (23), and does not affect other terms in equation (33). Also, note that adding diminishing utility in either instruction or public good research does not affect any of the qualitative results developed above compared to the linear case because concavity of the utility function in instruction and public good research does not affect the signs of any of the terms in equations (32) and (33).
Implications of Increasing Government Transfers to Universities

The case of increasing government transfers to universities presents a useful contrast to the case of increasing the royalty rate on private good research. Differentiation of (21) and (22) with respect to $g$ obtains

\[
L_{s} = u_{s}y_{g} + u_{s}y_{s} + u_{s}y_{s} > 0 \quad (27')
\]

\[
L_{z} = u_{z}y_{g} + u_{z}y_{s} + u_{z}y_{s} > 0. \quad (28')
\]

Positivity of (27') and (28') follows from $h_{g} = -1$ and $h_{xg} = h_{yg} = h_{zg} = 0$, and comparative static analysis of the budget constraint, \((\partial \pi / \partial y) dy + (\partial \pi / \partial g) dg = 0\), which implies

\[
y_{g} = dy/dg = -1/(r - h_{g}) > 0. \quad (29')
\]

Further differentiation either of (21) and (22) or of (29') reveals unambiguously that

\[
y_{s} = -(h_{xy} + h_{yy} y_{x})/(r - h_{x})^{2} > 0,
\]

\[
y_{z} = -(h_{xz} + h_{yz} y_{z})/(r - h_{x})^{2} > 0.
\]

These definite signs stand in contrast to Lemma 3, and verify the unambiguous signs in (27') and (28') regardless of linearity of utility.

Analyzing the effect of increasing government transfers in a manner parallel to the analysis of increasing the royalty rate, application of Cramer’s rule reveals

\[
dx/dg = (1/D)(L_{s} L_{zg} - L_{z} L_{sg}) = (1/D)(L_{z} L_{sg} - L_{s} L_{zg}),
\]

\[
dz/dg = (1/D)(L_{s} L_{zg} - L_{z} L_{sg}).
\]

Under the conditions of Lemma 1(a), these results imply that an increase in government transfers causes both instruction and public good research to increase \((dx/dg > 0\) and \(dz/dg > 0\)) in addition to the increase in private good research reflected by (29'). Thus, these results are in sharp contrast to those of Proposition 1(a).

Implications of the Bayh-Dole Act of 1980

The Bayh-Dole Act of 1980 substantially altered the incentives for IPR protection and distribution of income from discoveries financed completely or
partially by the federal government by giving the income-generating rights to the non-federal partner – typically a university. Also, the extension of patent protection by the U.S. Patent and Trademark Office to microorganisms, plants, and animals in the 1980s provided additional opportunities for universities to appropriate the benefits from research discoveries, especially in transgenetics and other bioengineered materials. These policy changes were regarded as a means of enhancing university funding with government budget neutrality. Our results here suggest, however, that the incentive implications may be far from neutral. The direct effect has been to increase the expected marginal return on private good research discoveries by permitting universities to engage in direct sales of patents and property rights, or in selling rights to the associated commercialization. But if universities face fixed budget constraints, or if new opportunities for earning profit from private good research induce more shifting of university effort relative to the additional funds they generate, then the more general development of public goods that benefit consumers and producers directly may be curtailed as an indirect effect.

The fixed-funding model of this chapter has important implications for how a university’s effort to develop privately appropriable market goods may change the composition of university instruction and research activities. Proposition 1 gives a set of conditions where the university is induced to not only shift its output mix relatively toward private good research as would be expected, but to reduce the absolute level of instruction and public good research. The implication is that the traditional activities attributed to universities – instruction and the development of public good research results that facilitate private good research in the private sector – are displaced. If so, then universities move into competition with private sector R&D in private good discovery and leave society with less of the traditional university outputs that represent investment in future productivity.

As a further effect, because the supply of instruction is reduced, tuition rates are possibly increased. The net effect on tuition rates depends on the relative effects of instruction and public good research in student demand, but according to the primary student demand relationship, a reduction in instruction is achieved by raising the tuition rate. As a university reduces public good research emphasis, reputation falls and the demand for university instruction declines. But assuming the latter effect is relatively weaker than dependence of student numbers on tuition rates, these results offer one explanation for the rapid rise in tuition rates that has occurred as the return on private good research has increased.

These effects of increasing the royalty rate are in sharp contrast to the case of increasing government transfers, which always induce a balanced growth in instruction, private good research, and public good research (in the sense that all three increase). Assuming that the primary effect on tuition rates is through the price-quantity demand relationship between tuition rates and student numbers, an increase in government transfers also lowers tuition rates by increasing the implicit supply of instruction.
Implications of Increasing Royalty Returns in
Steady State Equilibrium

Next we consider comparative static analysis of the long-run steady state model. Because complete comparative dynamic analysis of the general model of this chapter is not tractable, comparative static analysis of the corresponding steady state model is useful for understanding the implications of endogenous funding. For this purpose, we collapse the two-period model into a one-period model with endogenous university funding. Specifically, government transfers to support instruction are represented as a function of the steady state instruction level, \( g^x = g^x(x) \). Government transfers and grants for private good research plus private contracts with the private sector for private good development are represented by \( g^y = g^y(y, r) \). And government transfers and grants for public good research plus private donations that depend on reputation and performance in public good research are represented by \( g^z = g^z(z) \). As above, each of these transfer functions are assumed to be increasing and weakly concave in their arguments. Also, for obvious political and economic efficiency reasons, marginal increases in these transfers are assumed to be no more than the marginal cost of increasing the activities they support, \( g^x_c < c_x \), \( g^y_c < c_y \), and \( g^z_c < c_z \). Again, although transfers are usually for restricted uses, universities are assumed to have flexibility in allocation of their funding given that some funds are unrestricted and that faculty effort is unobservable.

The university utility maximization problem is thus represented by (19) and (20), but now \( h \) is defined by

\[
 h(x, y, z) = c(x, y, z) - t(x, z) - g^x(x) - g^y(y, r) - g^z(z),
\]

where \( h \) thus satisfies qualitative properties with respect to \( x, y, \) and \( z \) similar to the \( h \) in (6) where respective current and future variables are combined:

\[
 h_x = c_x - t_x - g^x > 0, \quad h_y = c_y - t_y - g^y > 0, \quad h_z = c_z - t_z - g^z > 0, \quad h_{xy} = c_{xy} - t_{xy} - g^x > 0, \quad h_{yz} = c_{yz} - t_{yz} - g^y > 0, \quad h_{xz} = c_{xz} - t_{xz} - g^z > 0, \quad h_{yy} = c_{yy} < 0, \quad h_{yz} = c_{yz} < 0, \quad \text{and} \quad h_{xz} = c_{xz} - t_{xz} < 0.
\]

Accordingly, all first- and second-order conditions hold as in the static model, and all of the results in equations (24)–(26) follow. The only difference is in the further results that depend on circumstances and related marginal effects of \( r \).

More explicitly, (24) and (25) can be represented as

\[
 y_x = dy/dx = h_x/(r - h_y) = (c_x - t_x - g^x)/(r - c_y + g^y) < 0, \tag{24''}
\]

\[
 y_z = dy/dz = h_z/(r - h_y) = (c_z - t_z - g^z)/(r - c_y + g^y) < 0, \tag{25''}
\]
which correspond to the negative of equations (17) and (18) where $\delta = 1$ because discounting is eliminated in the steady state. Thus, as in (17) and (18), endogenizing university funding causes the denominators of ($24''$) and ($25''$) to be lower in absolute value compared to the fixed-funding case because of the marginal response of private good research transfers to university efforts in private good research. Also, as argued regarding the implications of (17) and (18), both $y_x$ and $y_z$ increase in magnitude (negatively) if these marginal transfer effects sufficiently dominate the marginal effect of university efforts in instruction and public good research on transfers due to public interest lobbying and private donations in the numerators, respectively.

**Lemma 5**: Assuming that the lobbying effects of private industry sufficiently dominate those of lobbying efforts in the public interest ($y_x^{*} >> g_x^{*}$ and $y_z^{*} >> g_z^{*}$), the effect of endogenizing the political economy of university funding is to increase the marginal rates of substitution of private good research for both instruction and public good research for every output mix.

**Proof**: Because $y_x$ and $y_z$ are the negatives of the marginal rates of substitution of private good research with instruction and public good research, respectively, the effect of endogenizing the political economy of university funding is to increase the substitution of private good research for the more traditional university outputs of instruction and public good research for every output mix.

Proceeding further by analogy with the static model, endogenizing university funding does not alter Lemma 2. The only modification of Lemma 1 is that additive separability and linearity of $c(y, y, z) - g^{*}(y)$ rather than $c(y, y, z)$ matters. Thus, Lemma 1(a) also requires linearity of $g^{*}$. Also, sufficiently diminishing marginal transfers from increased private good research is a possible condition leading to the conclusion in Lemma 1(b).

With respect to the implications of increasing royalty returns on private good research, the effects are more dramatic. Comparative static analysis of the budget constraint with respect to $y$ and $r$, $(\partial \pi/\partial y) dy + (\partial \pi/\partial r) dr = 0$, now reveals

$$y_r = dy/dr = -(y + h_y)/(r - h_y) = -(y + g_y)/r - c_y + g_y^{*} > 0.$$

In this expression, one finds for any given output mix that both (i) the numerator increases according to the additional leverage provided by royalties for inducing universities to do private good research in response to lobbying efforts, $g_y^{*}$, and (ii) the denominator decreases in absolute value by the marginal effect of private good
research on government transfers for private good research due to private industry lobbying, $g_y^x$. This proves:

**Lemma 6**: Endogenizing the political economy of university funding increases the positive response of private good research to the royalty rate on private good research compared to the case of exogenous university funding for every output mix.

Further, differentiation of (21) or (29") using the definition of $h$ in this case further reveals

$$y_y = \{y_r [c_{yy} + (c_{yy} - g_y^x) y_x] - y_x/(r - c_y + g_y^x),$$

(30")

and differentiation of either (22) or (29") reveals

$$y_z = \{y_r [c_{yz} + (c_{yz} - g_y^z) y_x] - y_x/(r - c_y + g_y^z).$$

(31")

In both (30") and (31"), the effect of endogenizing funding for any given output mix is to decrease the denominators in absolute value, to increase $y_r$ in the numerators, and, under the conditions of Lemma 5, to increase $y_x$ and $y_z$ in absolute value in the respective numerators. This only magnifies the quantitative responses without changing any of the qualitative results of Lemmas 3 and 4, with the provision that sufficiently diminishing private research transfers ($g_y^x << 0$) can also lead to the conclusions in Lemma 3(a) and 3(b), while Lemma 3(c) also requires linearity of $g_y$.10

To consider how the response of instruction and public good research to an increase in the royalty rate on private good research is altered by endogenizing university funding, note that (32) and (33) remain applicable. Because both the numerator and the denominator ($D$) of these expressions change, we examine only the effects on (32) and (33) in the special case where the utility function is linear and the cost function is additively separable and linear in private good research.

**Proposition 3**: Suppose (i) the utility function is linear, (ii) the complementarity of public good research and instruction is strong either in the cost function ($c_{xz} << 0$) or the tuition revenue function ($t_{xz} >> 0$), and (iii) the cost function is additively separable and linear in private good research.

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9 While mathematically one might suppose the denominator effect could be great enough to cause a change in sign, this case is implausible because it makes $y_x$ and $y_z$ positive, thus violating the first-order conditions in (21) and (22), respectively.

10 However, it may be noted that augmenting $c_{xy}$ with $g_{xy}^x$ in the numerator of (30") makes the term $(c_{xy} - g_{xy}^x) y_x$ more likely to override other terms in determining the sign of the numerator, i.e., more likely to make the numerator negative, and thus the sign of $y_{xz}$ positive. But this possibility does not apply under any of the conditions in Lemma 3.
and linear in private good research. Then endogenizing university funding magnifies the negative effect of the royalty rate on both instruction and public good research.

**Proof:** Under the conditions of Proposition 3, one finds that \( L_y = u_y y_y , L_p = u_y y_p , y_y = h_y / (r - h_y) , \) and \( y_p = -y_i / (r - h_i) \) for \( i , j = x , z \). Assume for the moment that lobbying on behalf of the public interest is ineffective \( (g^r_x = g^r_z = 0) \) and that the royalty rate does not have a direct effect on marginal private research transfers \( (g^r_r = 0) \). Then \( \theta = 1 / (r - h_r) \) so that endogenizing university funding (adding effective lobbying on behalf of industry) changes \( \theta \) from \( \theta = 1 / (r - c_r) \) to \( \theta = 1 / (r - c_r + g^r_r) \). By inspection of the relevant equations above, one can verify for every output mix that \( y_{x} , y_{z} , y_{r} , y_{xx} , y_{zz} , y_{xx} , L_{xx} , L_{zz} , \) and \( L_{xz} \) each increase proportional to \( \theta \); and \( y_{xr} , y_{zr} , L_{xr} , L_{zr} , \) and \( D \) each increase proportional to \( \theta^2 \). As a result, \( dx/dr \) and \( dz/dr \) in (32) and (33) each increase proportional to \( \theta \). By generalizing this derivation, it is further clear that adding public interest lobbying effects \( (g^r_x > 0 , g^r_z > 0) \) and a direct effect of the royalty rate on marginal private research transfers \( (g^r_r > 0) \) relaxes the direct proportionality of these changes, but does not change the qualitative implications under the conditions of Lemma 5.

**Further Discussion of the Implications of the Bayh-Dole Act**

The results of this chapter develop reasonably plausible conditions under which the increased return to private good research in universities tends to displace instruction and public good research, both relatively and absolutely. This redirection of university resources can be expected to create socially undesirable crowding-out of some private good research that would otherwise be undertaken by the private sector at private expense, while forgoing public good research discoveries and education that are needed to enhance the productivity of future private good research. Coffman, Lesser, and McCouch (2003), for example, discuss how the Bayh-Dole Act and the new incentives for privatizing discoveries in plant breeding have brought a major reduction in public-private exchanges of germ plasm needed for research and open science. From a longer run perspective, private good discoveries with private applications depend on the availability of underlying public good research discoveries that tend to occur in universities rather than the private sector. The reason is that private returns to such discoveries are harder to secure in private markets. Altering incentives so that university research as well as private industry responds to private profit incentives in the short run, along with the associated indirect influence of (declining) public support for legislative funding of universities, may result in a reduced pool of basic knowledge to support private good research in the long run, which can be expected to reduce economic productivity in the future.
In addition, the alternative interpretation of variables in the models of this chapter, whereby $y$ is private good research and $z$ is public good research, raises an important issue about the extent to which applied research tends to develop private goods and basic research tends to develop public goods. A potential indirect effect of the Bayh-Dole Act is that basic research discoveries that might otherwise be disseminated freely when royalties do not drive university behavior ($r = 0$) might be withheld for the purpose of generating as many private good patents as possible before release. For example, if a new basic research discovery promises to facilitate several private good research discoveries that can be patented, then a university may be better off keeping the basic discovery as a “trade secret” much as is done by private companies with their R&D discoveries. Nelson (2003) suggests that this type of outcome will severely undermine the “intellectual commons” of public goods research at universities. Thus, some of the broader applied research discovery that it might generate through public dissemination may be foregone. Also, a particular scientist may be induced to privatize a discovery by leaving university employment and developing its implementation in the private sector rather than publishing it in academic journals. A similar phenomenon may also apply to some private good research discoveries. Before the Bayh-Dole Act, applied research discoveries by universities were largely local or state-specific public goods. Because benefits were widely dispersed, local public support, including both producer and consumer interest groups, was sufficient to ensure that public universities were effectively funded.

The point is that the categorization of either applied or basic research discoveries into those that develop private versus public goods should likely be treated as an endogenous decision that depends largely on how the discoveries are treated once they are made. If the rewards for privatization are greater because of royalty access, then economic incentives suggest that relatively more research discoveries will be kept private to reap the potential royalties. Recognizing this endogeneity of choice for dissemination of research results, the increased interest of universities in royalty income may cause an even greater shift toward private good research than depicted by the models of this chapter.

### Behavior of Private versus Public Universities

The model of this chapter also has implications for the difference in response of public and private universities to increased royalty incentives for private good research. Public universities in the U.S. are state institutions, which are

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11 Ehrenberg (2002) describes key differences in the organization of public and private universities. In public universities, the board of regents (trustees) are appointed by the state governor or legislature. The state appropriation to a university must compete with other state government uses of funds, e.g., public schools, roads and highways, police protection, welfare. Hence, the board of regents (trustees)
financed in part by direct funding from state governments for instruction, research, and outreach. Private universities receive less if any statutory support from state government transfers but, instead, are more dependent on tuition revenue to finance instruction, and do not receive significant state government transfers for outreach activities (outreach activities may be viewed as part of the university’s production of public goods). The latter is particularly true when the comparison is to land-grant universities. Accordingly, private schools typically have high tuition rates, and thus higher and possibly positive $t_x$.

To consider the case of a private university compared to a public university, suppose in the case of a private university that equation (34) is replaced by

$$h(x, y, z) = c(x, y, z) - t_x(x, y, z) - \phi g^x(x) - g^y(y, z) - \psi g^z(z),$$

where $t_x > 0$, and public transfers for instruction are a fraction $\phi$ of what they are for a comparable public university, $0 < \phi < 1$ ($\phi = 0$ if education is funded entirely from tuition), and public transfers for public good research and outreach are reduced to a fraction $\psi$ of what they are for a comparable public university or land-grant university, $0 < \psi < 1$. Deriving equations similar to (24) and (25), or (17) and (18), for this case obtains

$$u_x = c_x - \phi t_x - \psi g^x_x = -y_x,$$  \hspace{1cm} (17')

$$u_y = c_y - r - g^y_y = -y_y,$$  \hspace{1cm} (18')

From these results, the lower funding for outreach activities in private universities, represented by reducing $\psi$ below 1, causes the numerators of both (17') and (18') to increase, which implies that private universities substitute private good research for both instruction and public good research/outreach compared to public universities, and particularly compared to land-grant universities. Similarly, the relatively heavier dependence on tuition revenues for funding of instruction, represented by a reduction of $\phi$ below 1, causes the numerator of (18') to increase, which implies that private universities substitute private good research for public good research relative to public universities. While in (17') the reduction in $\phi$ suggests that the numerator of public universities must answer to the executive and legislative branches of the state government, which impose severe restrictions on university expenditures and cost increases. The board of trustees of a private university are responsible only to themselves and are frequently alumni of the institution for which they serve. Hence, they are likely to be very quality conscious and to see cost as quite secondary (Ehrenberg 2002, pp. 23–26).
might decrease if \( t_x < 0 \), the accompanying fact that tuition rates of private universities are higher will tend to make the numerator of (17') higher as well, as is definitely the case if private universities charge high enough tuition rates that student demand is elastic \( (t_x > 0) \). Thus, it is not surprising to find top private universities ranking near the top among all universities with respect to revenues from patents and royalties.

Turning to the comparative static implications of an increase in the royalty rate on private good research, these larger magnitudes of \( y_x \) and \( y_z \) for private universities have further implications. Increasing \( y_x \) and \( y_z \) in (30") and (31") magnifies only the quantitative responses without changing any of the qualitative results of Lemmas 3 and 4, again with the provision that sufficiently diminishing private research transfers \( (g_{xy}^x << 0) \) can also lead to the conclusions in Lemma 3(a) and 3(b), while Lemma 3(c) also requires linearity of \( g_y \). Thus, the response of instruction and public good research to an increase in the royalty rate on private good research represented by (32) and (33) can be expected to be higher in private universities than public universities, and particularly higher than in land-grant universities that have considerable government funding of outreach activities. Specifically, in the special case emphasized in this chapter, the following proposition follows.

**Proposition 4**: Suppose (i) utility function is linear, (ii) the complementarity of public good research and instruction is strong either in the university cost function \( (c_{xz} << 0) \) or tuition revenue function \( (t_{xz} >> 0) \), (iii) the cost function is additively separable and linear in private good research, and (iv) student demand is elastic at the high tuition rates of private universities but inelastic at the lower tuition rates of public universities. Then, comparing universities with identical utility and cost functions, an increase in the royalty rate will induce a greater displacement of instruction and public good research by private good research in private universities than public universities, and in general public universities than land-grant universities.

**Proof**: Again, under the conditions of Proposition 3, which apply in this proposition, one finds that \( L_y = u_y y_y, L_w = u_y y_w, y_y = h_y/(r - h_y) \), and \( y_w = y_i/(r - h_i) \) for \( i,j = x,z \). Thus, from (32),

\[
\frac{dx}{dr} = \frac{1}{r - h_y} h_x (c_x - t_x - \psi g_z^x) + h_z (c_z - t_z - \psi g_z^z) - \frac{h_z}{h_x} g_z^x h_x, \]

which implies

\[
\frac{d^2x}{dr d\psi} = \frac{u_y^2}{D (r - h_y)^3} \left[ h_x g_z - g_z h_x + \frac{dx}{dr} g_z h_x (r - h_y) \right].
\]
The first and third terms in brackets are negative and dominate the second term under condition (ii) of the proposition, while the term outside brackets is negative. Thus, the effect of reducing $\psi$ is to make $dx/dr$ more negative. A similar approach applies to proving the remaining assertions of the proposition.

The results of this section thus suggest a further exacerbation of effects of the Bayh-Dole Act among private universities compared to public and land-grant universities. In summary, the new science policy that began in the 1980s seems likely to have increased incentives for private good research relative to public good research in private universities by more than in public universities. (Of course, these same results suggest that private universities may have faced relatively weaker incentives for private good research discoveries than public universities before 1980 as well, as was apparently the case in reality.)

**Empirical Evidence**

In this section, we summarize general evidence about trends in university sources of funds and expenditure allocations in recent times. General summary data compiled by the Association of University Technology Managers (AUTM) since 1992 are presented for a panel of 73 public and private universities in Table 1. The list of universities included is presented in Appendix Table 1. The panel data set includes 73 universities (22 private and 51 public), of which 20 are land-grant schools. The size of the panel is limited by university OIPs reporting to AUTM.

Each university’s “total current expenditure” is defined so as to exclude hospital expenditure. This is done to increase the similarity of expenditures compared across universities because a university hospital, when present, is a major expenditure component (U.S. Department of Education 2000, Table 337). Less than one-half of the 73 universities in our data set operate a hospital. Table 1 presents information on total university expenditure and its components averaged across universities for private, public land-grant, and other public university groups. Table 2 presents the same information for revenue and its components. While the data do not include a variable representing the royalty rate, the data permit a cursory comparison to the predictions of the model of this chapter under the assumption that the royalty rate for universities has increased due to the Bayh-Dole Act. The expenditure data in Table 1 permit a comparison of impacts on tuition versus research, and the revenue data in Table 2 permit a comparison of the effects.

While Table 1 shows remarkable upward trends in both instruction and research expenditures for private universities, the increase in expenditure on research relative to instruction has increased by 56 percent, suggesting a significant displacement of emphasis on the traditional university activity of instruction. A strong but smaller increase (44 percent) in research relative to instruction has also taken place among other public universities, although the increase was mostly after 1999 whereas the
rapid increase among private universities was earlier. The increase in research relative to instruction has been much less (21 percent) for land-grant universities. While the expenditure data do not permit comparison of public good research versus private good research to instruction, they certainly verify a displacement of instruction by research that is consistent with the predictions of Proposition 1 and specifically consistent with the predictions of Proposition 2 for the case where the two forms of research are complementary. Also, the ordering of impacts whereby the effect on private universities is largest and the effect on land-grant universities is smallest is consistent with the predictions of Proposition 4.

The data on public service expenditures relative to instruction is also interesting. For private universities, this ratio has fallen from a very low relative share, while it has remained strong and even increased for land-grant universities, and has increased rapidly to significant levels for other public universities. These results suggest a reduction in emphasis on public goods in private universities consistent with Proposition 1 given the relative displacement of instruction with research.

Turning to the revenue data in Table 2, the most dramatic trend is the increase in reliance on private funding among private universities.\(^\text{12}\) The implied relative displacement of tuition revenues with private funding is the most important implication of Proposition 1. Also noteworthy is the displacement of state funding with federal funding, which specifically qualifies for the Bayh-Dole property rights for discoveries. For land-grant and other public universities, private funding has increased relative to tuition as suggested by Proposition 1, but at a much lower rate, consistent with Proposition 4. In each case, state funding has declined relative to tuition although the reduction has been much greater for other public universities than for land-grant universities. This may well suggest a reduction in local public support that has occurred in response to universities increasingly serving private interests. Not surprisingly, this displacement has been slower for land-grant universities where state funds have more specific purposes (experiment station and extension) and commitments to outreach (extension) are greater.

While these results can be regarded as cursory at best, they suggest some clear trends that appear to be consistent with the implications of the model in this chapter. Thus, they call for a more careful and complete econometric analysis of this and related data in a structural model that can test both implications and critical structural parameters that give rise to specific results.

\(^{12}\) In both Tables 1 and 2, the component of revenue not shown explicitly has a sharp upward spike in 1999 in the case of private universities due to unusually high returns from endowments invested in the stock market. This same spike carries over to expenditures as well. Ehrenberg (2002) describes how in the 1990s, when the stock market was booming and private university endowment values were skyrocketing, parents of undergraduate students revolted against private universities' tuition rates rising faster than the rate of inflation. This action was apparently strong enough to cause these universities to draw on endowment funds for student aid and reduce the rate of tuition increases in the late 1990s. However, after the stock market weakened, private universities cut their scholarship rates.
Conclusions

This chapter has presented a new conceptual model of university behavior. It treats a university as a utility-maximizing institution subject to exogenous or endogenous resource constraints. The model shows how an increase in the expected payoff of patenting due to events first started in the early 1980s of private good research discoveries can be expected to change the composition of universities’ activities both in the short and long terms. Although making patent income available to universities was viewed as a government budget-neutral way to improve the financing of universities, the results identify specific plausible conditions under which the incentives of pursuing patent income leads to an absolute reduction as well as a relative reduction in instruction and public good research. In these circumstances, the overall effect is to reduce the overall investment in education and basic research, including the intellectual commons, that can be expected to fuel long-run growth in the economy. Based on these results, this chapter presents interesting new testable hypotheses and highlights the key parameters on which these results depend.

Finally, we used a panel data set of public and private universities to provide the observations for an initial cursory test of our conceptual model. With a panel of 73 public and private universities, we showed that patterns in allocation of expenditures and sources of revenue have changed dramatically from 1990 to 2001. The major dramatic trends are highly consistent with the implications of the model and suggest some important concerns for future funding of universities, the future stock of public research output, and the growth rate of the intellectual commons. While not considered here, the results also suggest important concerns for the growth of university tuition rates.

A major purpose of the theoretical exercise of this chapter was to focus attention on the elasticities of substitution and technical transformation that are critical in determining how serious are the quantitative effects of university patent rights. By future empirical work based on this model, we hope to obtain a better understanding of public-private partnering and the relationships between public and private research, and a more quantitative representation of the model. For example, current empirical work does not provide definitive evidence on whether public and private research are complements or substitutes (David, Hall, and Toole 2000). Other possibilities for generalizing the model include a game theoretic approach to modeling competition among universities as each seeks a niche in the spectrum of possibilities of output specialization, from liberal arts colleges focused on education to prestigious private universities heavily oriented toward discovery and patent income.
References


Table 1. Mean Expenditures and Expenditure Composition by University Groups, 1990-2001a

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Source: Association of University Technology Managers (AUTM)

a See Appendix Table 1 for the list of universities in each group. Total university expenditure is defined as “total current fund revenue” less hospital expenditures.
b Expenditures allocated to other uses, which account for remaining total expenditures, are not listed explicitly.
### Table 2. Mean Revenues and Revenue Components by University Groups, 1990-2001

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<td>374</td>
<td>482</td>
<td>66</td>
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<tr>
<td>Revenue Components$^b$</td>
<td></td>
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<tr>
<td>Tuition and Fees</td>
<td>45</td>
<td>66</td>
<td>72</td>
<td>63</td>
<td>42</td>
</tr>
<tr>
<td>Federal grants, contracts, and appropriations</td>
<td>49</td>
<td>60</td>
<td>66</td>
<td>74</td>
<td>52</td>
</tr>
<tr>
<td>State grants, contracts, and appropriations</td>
<td>125</td>
<td>120</td>
<td>126</td>
<td>112</td>
<td>-10</td>
</tr>
<tr>
<td>Private gifts, grants, and contracts</td>
<td>16</td>
<td>20</td>
<td>26</td>
<td>30</td>
<td>83</td>
</tr>
<tr>
<td>Relative Shares</td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Federal/Tuition and Fees (%)</td>
<td>110</td>
<td>92</td>
<td>91</td>
<td>118</td>
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<tr>
<td>State/Tuition and Fees(%)</td>
<td>282</td>
<td>183</td>
<td>175</td>
<td>178</td>
<td>-37</td>
</tr>
<tr>
<td>Private/Tuition and Fees (%)</td>
<td>37</td>
<td>31</td>
<td>36</td>
<td>47</td>
<td>29</td>
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</tbody>
</table>

Source: Association of University Technology Managers (AUTM)

$^a$ See Appendix Table 1 for the list of universities in each group. Total university expenditure is defined as “total current fund revenue” less hospital expenditures.

$^b$ Income from endowments and other sources is not shown explicitly, which would otherwise account completely for total revenues.
# Appendix Table 1. List of 73 Universities in the Association of University Technology Managers Data Set

<table>
<thead>
<tr>
<th>Private</th>
<th>Public Land-Grant</th>
<th>Other Public</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brigham Young University</td>
<td>Clemson University</td>
<td>Florida State University</td>
</tr>
<tr>
<td>California Institute of Technology</td>
<td>Colorado State University</td>
<td>Georgia Institute of Technology</td>
</tr>
<tr>
<td>Case Western Reserve University</td>
<td>Cornell University</td>
<td>Indiana University–Bloomington</td>
</tr>
<tr>
<td>Columbia University</td>
<td>Michigan State University</td>
<td>Ohio University–Main Campus</td>
</tr>
<tr>
<td>Dartmouth College</td>
<td>Mississippi State University</td>
<td>SUNY at Albany</td>
</tr>
<tr>
<td>Emory University</td>
<td>Ohio State University</td>
<td>SUNY at Bingham</td>
</tr>
<tr>
<td>Harvard University</td>
<td>Oregon State University</td>
<td>SUNY at Buffalo</td>
</tr>
<tr>
<td>Johns Hopkins University</td>
<td>Pennsylvania State University</td>
<td>SUNY College of Env. Science &amp; Forestry</td>
</tr>
<tr>
<td>Massachusetts Institute of Technology</td>
<td>University of Arizona</td>
<td>SUNY at Stony Brook</td>
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<tr>
<td>Northwestern University</td>
<td>University of Arkansas</td>
<td>University of Akron</td>
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<tr>
<td>Princeton University</td>
<td>University of California–Berkeley</td>
<td>University of Alabama/Birmingham</td>
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<td>University of California–Irvine</td>
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<td>University of Connecticut</td>
<td>University of California–Los Angeles</td>
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<td>Temple University</td>
<td>University of Delaware</td>
<td>University of California–Riverside</td>
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<td>Tulane University of Louisiana</td>
<td>University of Illinois, Urbana–Champaign</td>
<td>University of California–San Diego</td>
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<td>University of Chicago–(ARCH Dev. Corp.)</td>
<td>University of Maryland–College Park</td>
<td>University of California–San Francisco</td>
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<td>University of Missouri–Columbia</td>
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<td>Yale University</td>
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