Modeling research universities: Predicting probable futures of public vs. private and large vs. small research universities

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The future of the American academic research enterprise is considered. Data are presented that characterize the resources available for the 160 best-resourced research universities, a small subset of the 2,285 4-year, nonprofit, higher education institutions. A computational model of research universities was extended and used to simulate three strategic scenarios: status quo, steady decline in foreign graduate student enrollments, and downward tuition pressures from high-quality, online professional master's programs. Four specific universities are modeled: large public and private, and small public and private. The former are at the top of the 160 in terms of resources, while the latter are at the bottom of the 160. The model's projections suggest how universities might address these competitive forces. In some situations, it would be in the economic interests of these universities to restrict research activities to avoid the inherent subsidies these activities require. The computational projections portend the need for fundamental change of approaches to business for universities without large institutional resources.

research universities | computational model | strategic scenarios

Top American research universities, both public and private, have enjoyed remarkable success, capturing significant shares of federal dollars available to support research and expanding their influence and significance within American higher education. Over recent decades, however, the financial circumstances of all colleges and universities have changed. Pressures include declining public tax-based support, increased tuition and fee structures, complex tuition-discounting programs, sophisticated need-based financial aid mechanisms, accelerating costs of institutional operations, and competition for fee-paying international students. Massively open online classrooms (MOOCs) have matured and, enabled by the internet, become pervasively accessible and steadily less expensive in terms of costs per student.

These forces have contributed to the many challenges faced by research universities (1, 2), while also creating opportunities for fundamental change of all institutions of higher education (3–5). This may substantially expand the number of students seeking education (6). Indeed, there are frequent articles in *The Economist*, *The New York Times*, *The Wall Street Journal*, and other serious publications raising numerous issues about higher education. Some worry that research institutions may be at risk.

In addressing these issues, it is important to emphasize that American higher education includes many institutions that are substantially different in their organization, personnel composition, financial structures, opportunities, and expectations. Each of the institutions may respond in significantly different ways to the current and likely future financial and demographic pressures. The traditional model of tenured professors is already being seriously modified at many institutions (7), and the ability of many universities to sustain a significant research presence may decline. Demographic trends will also have an impact, although the National Center for Education Statistics (8) projects continued stability and growth in the college age population through 2025.

Over time, the current higher education marketplace will likely evolve into distinct operational sectors following different priorities (whatever their public relations rhetoric). A wide range of quantitative indicators illustrate how much of that transformation is already well underway, even though the process is obscured by a media focus on elite institutions.

This article first uses historical data to identify long-standing trends in institutional performance. This is the perspective of the Center for Measuring University Performance (MUP) project (9, 10). We then consider forces that may radically restructure the academic marketplace over a period of years. This will involve using the computational model presented and extended in this article (11).

By connecting these perspectives—a historical view contributing to the prospective economic model—we offer a systematic exploration of possible changes in university behaviors involving the various elements of the finances and operations of universities. We computationally project the impacts of increased competition for students, grants, publications, and other elements associated with these institutions. These projections enable discussing how universities can respond to anticipated changes. Elsewhere, we have elaborated this perspective to address the entire higher education marketplace (9).

Characterizing the Competition Among Top Research Universities

We first focus on those research universities that define prestigious university brands. To begin, we need to emphasize that most university research, and especially scientific research, will remain an institutional loss leader. There are several reasons for this: costs of securing grants and contracts are not reimbursable; revenue generated does not fully pay for the costs of producing the research; actual indirect costs exceed external reimbursements;

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and transactional costs of dealing with the government inflate indirect costs (12).

An additional consideration is the extent to which sponsored research projects subsidize education by paying tuitions for graduate students. There are 40,000 science, technology, engineering, and mathematics (STEM) PhD graduates annually, so the total number of STEM PhD enrollees is roughly 160,000 (13). In total, 82,650 of these students receive tuition remissions (14). The other 48% receive discounts, that is, in-state tuitions, or pay a larger portion of the list price tuition. Assuming $10,000 as an average for these 77,350 students, there are total tuition expenditures of $774 million annually. Eighty-four percent of the 160,000 PhD students are in the 160 institutions (9). The total federally sponsored research expenditures of the 160 institutions are roughly $34 billion (9). Consequently, a bit less than 2% of the $34 billion is spent on tuition.

Thus, the impact of tuition paid for PhD students by sponsored projects is small and would have little impact on the overall projections in this article. The largest unfunded cost of research is the typical half-time release provided for faculty to pursue research. Grants pay for the auditable costs of conducting proposed research after grants are awarded, not for the costs of background research and preparing proposals. Companies include costs of sales in their prices. Universities do not and are not allowed to do so. Therefore, they do not recover these costs.

A wide variety of other research support provided by the university, whether for released time from teaching, facilities not covered by project awards, equipment and personnel costs, or other institutional support, receives no external funding. In the increasingly resource-constrained environment, the financial model that has supported the current scale of America's dynamic research universities environment seems unsustainable.

While research generates an increasing net cost to institutions, it may not follow that current research universities will reduce their commitment to research within a more economically rational approach to institutional finance. The most successful research universities compete to accumulate the highest level of quality elements within their institutional boundaries to achieve high brand value. In this article, brand value is defined in terms of faculty reputations, a metric for which is later provided. The institutions then use this brand value to attract the best students and faculty, funding, and other resources from the external marketplace to further expand their quality and enhance their brand.

This pursuit of brand value within the research university deserves more attention. These institutions function as quality engines. They transform dollars into reputations, and then transform reputations into dollars. Stinchcombe (15) convincingly argues this point in terms of universities renting talent, talent creating reputations (or brand value), and reputations attracting students and funding, creating a feedback cycle that is reflected in the model presented in this article.

Institutions try to capture the most nationally competitive quality elements possible. These elements include students, faculty, staff, facilities, and programs, but especially research faculty. Research capable faculty bring or attract a wide range of other quality assets, whether graduate students, competitive grants, research publications, postdoctoral researchers, or high-level scientific staff.

Because these high-performing faculty are in short supply relative to the demand from many research-competitive institutions, they command a significant investment. This investment is about salaries, facilities, support personnel, research infrastructure, and related faculty and programs. The prestige and significance, the brand value, of a research university is the result of the cumulative impact of these high-performing people (9). Furthermore, organizations with such resources have been found to have greater organizational and political power (16, 17).

Indicators of Research University Success

A primary indicator of research university success is the annual federally sponsored science and engineering research expenditures. This number is useful as an indicator of the cumulative research activity funded by federal funding agencies. Expenditure data are a better indicator than awards because it reflects 1 y of direct and indirect billed activity to a federal research grant (18). It is also a general proxy for the scale of institutional investment required to sustain research activities.

The competition is between individual faculty research proposals in a peer-reviewed context. These proposals are faculty proposals, and awards are primarily faculty awards, although they may have a wide range of linked institutional commitments. In practice, many proposals have multiple faculty participants, involve individuals from a number of institutions, and include linkages to corporations. Still, the core competencies that drive the success of the research university are the high-performing faculty members.

This competition places a burden on research universities that must recruit and retain nationally significant faculty to compete successfully for the national grants that define success. The institution's investment is often a high-risk investment because while it may be advantageous to recruit faculty who already have federally funded research grants, the marketplace does not offer a sufficient number of these individuals to meet demands. Thus, institutions must recruit younger promising faculty whose work offers the expectation of a successful research career. This promise is not always fulfilled (19), so the institutional investment in promising faculty involves a significant risk, which is addressed by the computational model.

Research universities cover this risk in a number of ways. The most obvious is through the tenure process that attempts over perhaps 5–6 y to identify which newly hired faculty members have the greatest likelihood of long-term research success. While this process lowers somewhat the risk associated with hiring and supporting a particular faculty member, the short time until the decision involves significant risk. This risk is managed in a variety of ways.

In institutions with large undergraduate populations, teaching and functions associated with extensive undergraduate, master's, or certificate programs provide an occupational niche for faculty whose research performance is no longer competitive. This approach is particularly relevant for large public research universities where the size of undergraduate student bodies and the growth of profitable programs buffer these universities against the risk associated with providing tenure to faculty candidates early in their research careers.

Since institutions rarely discount master's or certificate prices, these programs more than pay their own way. Other operations of the institution also subsidize research infrastructure, whether related to buildings, core support of energy costs, basic accounting and business services, security, legal, technology, and the like. The larger the university budget from all sources, the better able the institution is to support the costs of sustaining research.

In short, research universities seek revenue to create a financial base capable of sustaining the substantial unfunded costs of competitive research faculty, staff, and facilities. They use this financial base to acquire the highest level and volume of quality, defining its brand value. This brand attracts students, faculty, alumni, donors, granting agencies, foundations, and others.

Concentration of Research Performance

A review of the performance of highly competitive research universities shows a remarkably stable profile. Lombardi and Craig (10) identified 160 universities (public and private) with over $40 million in federal science and engineering expenditures in 2014. (Only single-campus universities were considered. Thus, the University of California, for example, was considered to be 10 universities.) This group represents about 19% of the academic institutions spending federal research funds and captures about 92% of the federal research expenditures reported by all institutions (Table 1). This relationship has remained quite stable for over a decade and a half.

Table 1. Federal research funding

Institutions reporting any federal research in past 5 y	2014, US$M (no. of institutions)	% Share	2010, US$M (no. of institutions)	% Share	2006, US$M (no. of institutions)	% Share	2002, US$M (no. of institutions)	% Share
Total federal research	36,882 (856)		36,386 (735)		29,971 (658)		21,731 (623)	
Over-$40M group	33,751 (160)	92% (19%)	32,942 (158)	91% (21%)	27,123 (150)	90% (23%)	19,700 (125)	91% (20%)

Note: Over-$40 million group based on 2014 federal research expenditures.

Research universities constitute a special category among the components of the American postsecondary industry. Their significance sometimes seems much greater than their participation levels in many parts of the higher education marketplace. Out of the 2,285 4-y, nonprofit higher education institutions, the top group of 160 research universities constitutes only 7% of the institutions and enrolls roughly 3.5 million students, representing only 18% of the 20.2 million students enrolled at all levels of public and private, nonprofit 4-y institutions. They represent an exceptionally prestigious cluster of universities, and their doctoral programs produce a constant stream of instructors and faculty throughout higher education (10).

Total research expenditures, including both federal and nonfederal funds, captured by the top institutions has declined from 25% in 2002 to 18% in 2014, likely the result of intense competition from less research-intensive institutions with good access to local and state funds and an increase in the number of institutions from which data are collected.

A strong institutional financial base is necessary for the support of competitive research universities. Endowment assets serve as a proxy for institutional wealth. Philanthropy has long played a major role for American research universities (20). This is of course only an indicator but offers an illustration of the ability of institutions to capture a strong position within private fund-raising for endowment. The top institutions raise a steady 75% of all endowment assets (Table 2). The data on annual giving show a similar pattern.

Faculty quality is another indicator of research university success. One indicator is the number of National Academy members in each institution. National Academy members are heavily concentrated in the top research group. A steady proportion of 97% of the National Academy members are in the over-$40 million group, although only 69% of the institutions in this group have faculty with these distinctions. This is a reflection of the concentration of National Academy members in a small number of institutions. About one-half of these individuals are in the 14 institutions that have more than 100 National Academy members.

A second faculty indicator includes faculty who have received a variety of scholarly awards for distinction in a wide range of fields, not just those in the sciences and engineering (9). The over-$40 million institutions capture around 80% of the faculty awards even though they represent only 38% of all institutions having faculty with these awards. However, 259 institutions not in the over-$40 million group have high-quality faculty who win these awards, indicating less skew than in funding.

The selectivity of colleges is often linked to SAT scores or equivalent, serving as proxy indicators of institutional undergraduate selectivity. Research university brand advantage for recruiting high-SAT students is relatively less powerful than it is for recruiting faculty, as many colleges with minimal research but high brand value, based on faculty quality and undergraduate quality, secure a significant number of high-SAT applicants. The over-$40 million group has an SAT advantage of only 140 points over institutions outside this group, a premium of around 13%.

Scale is important in research university success. Larger scale spreads the costs of research over more projects, faculty, and research programs. Many research institutions have significant undergraduate student bodies whose numbers, through tuition, fees, state support, and alumni commitment, drive resources and support the teaching and other work associated with instruction. In many cases, research faculty with highly successful programs and full funding nonetheless teach students at the undergraduate and graduate level.

The top research universities have over one-third of the undergraduate and graduate students enrolled in institutions with any federal research expenditures. These top institutions have a somewhat lower percentage of undergraduates than the entire group, but a higher percentage of graduate students. The top research universities have about three times the median size of undergraduate and about four times the median size of graduate populations than the group as a whole.

With emphasis on graduate education, the top institutions in the over-$40 million group produce the smallest percentage of associate degrees, over one-third of bachelor's degrees, almost one-half of master's degrees, just over one-half of professional degrees, and over three-quarters of doctorate degrees.

Projecting the Research University into the Future

Major research institutions, while at little risk of failure, and operating competitive enterprises, struggle to maintain the scale of their operations. They engage in innovation, pursue opportunities by expanding technological capabilities, seek economies through outsourcing, pursue additional revenue opportunities, and constantly adjust their undergraduate programs to capture the best students while expanding diversity.

Research universities manage a wide range of product lines of varying profitability. Some generate net losses to the institution, including research and usually intercollegiate sports. Some generate profits including undergraduate enrollment for public institutions with state funding and significant alumni support, and stock market returns and private fund-raising for all institutions. A rational approach, typical of business enterprises, would surely underestimate the value of the intangible products created by universities. This intangible element is captured by what we call brand value. It is possible that the stress of the current financial

Table 2. Endowment and annual giving

Institutions reporting federal research dollars in past 5 y	2014, US$M (no. of institutions)	% Share	2010, US$M (no. of institutions)	% Share	2006, US$M (no. of institutions)	% Share	2002, US$M (no. of institutions)	% Share
Total endowment	483,957 (697)		328,020 (687)		318,623 (661)		208,413 (644)	
Over-$40M group	363,772 (155)	75% (22%)	245,603 (155)	75% (23%)	238,511 (150)	75% (23%)	152,043 (152)	73% (24%)
Total annual giving	30,110 (621)		22,666 (639)		22,022 (630)		18,737 (615)	
Over-$40M group	23,275 (153)	77% (25%)	16,940 (153)	75% (24%)	16,014 (144)	73% (23%)	13,875 (148)	74% (24%)

challenges will change the commitment to research, but whether these changes will produce a major reframing is not clear (10).

A Computational Model for Research Universities

Fig. 1 summarizes a computational model for research universities, discussed in great detail in a recent book (11), which enables exploration of relationships of many elements in the research university enterprise. Significant extensions of this model, reported here, enabled application of the model to specific public and private universities.

This model is based on a thorough analysis of a wealth of data pertaining to the various aspects of a university enterprise. This includes sources of funding, alternative publication outlets, predictors of brand value (and hence rankings), workforce structure, administrative practices, and the like. Student applications are driven by tuition and brand value. Expected degree completion time and potential job opportunities may play a role, but tuition and brand value dominate. Accepted students who enroll, as well as continuing students, determine needs for classes and faculty members to teach these classes, which drives the costs of teaching. Tenure track (TT) faculty members need to pursue research to achieve tenure and promotion. They need to write proposals to attract funding for their research.

The research activities of TT faculty members result in publishing research articles, which are eventually cited and, over time, increase faculty members' *h*-index, that is, the number of articles cited at least *h* times. The combination of articles published, citations of these articles, and *h*-index, over time, provides an estimate of brand value, which correlates closely with an institution's rankings. This estimate is a surrogate for rankings.

This is all complicated by several phenomena (11). Research funding is increasingly competitive, with funding decreasing relative to a steadily increasing number of proposals. Publication is increasingly competitive, with opportunities very constrained relative to a steadily increasing number of submissions. The result is faculty members have to work harder to achieve less success.

Research Publications. The probability of an article being accepted for publication is given by Eq. **1**:

$$PA = P_{OA} \exp(-\lambda_A NST), \quad [1]$$

where PA is the probability of acceptance, NST is the total number of articles submitted by all authors, and P_{OA} and λ_A are model parameters fit to data for different journals.

Data were collected for 17 y of the journal *Nature* (21), a compilation of 10 y of 50 *IEEE Transactions* (22), and 15 y of the relatively new *Journal of Systems Engineering* (23). The best-fit parameters (minimal root-mean-squared error) for Eq. **1** for this set of journals were determined, along with the annual growth rate of NST.

Cumulative citations of these articles are modeled by Eq. **2**:

$$NC(T) = NC_O [1 - \exp(-\lambda_C T)], \quad [2]$$

where NC (T) is the cumulative number of citations T years after publication and NC_O and λ_C are model parameters fit to citation patterns for different disciplines. For patterns averaged across all science and technology disciplines, the best-fit parameters (minimal root-mean-squared error) for Eq. **2** are NC_O equals 24 and λ_C equals 0.125 (24).

Cumulative citations, over time, can be used to compute a faculty member's *h*-index, denoted by HI. This index is defined as the number of published articles that have at least HI citations. For example, HI equal to 20 means that there are 20 articles with at least 20 citations. Article number 21 has, by definition, less than 21 citations. Otherwise, HI would be 21.

Research Proposals. The probability of a proposal being funded is modeled by Eq. **3**:

$$PF = P_{OF} \exp(-\lambda_F NPT), \quad [3]$$

where PF is the probability of funding, NPT is the total number of proposals submitted by all researchers, and P_{OF} and λ_F are model parameters fit to data for different funding sources.

Data were collected for 18 y of the National Institutes of Health (25) and 9 y of the National Science Foundation (NSF) (26). The best-fit parameters (minimal root-mean-squared error) for Eq. **3** were determined for these two agencies along with the annual growth rate of NPT.

If a faculty member submits NP proposals, at a cost of a percent of their time per proposal, then the number funded NF will be the product of PF and NP. It is assumed that a faculty member will submit the number of proposals that will assure an expected grant every other year. This assumption is easy to vary within the computational model.

Brand Value. Brand value is a proxy for rankings. We would like to use objective and inherently measurable attributes of a university that, when combined into a brand value index, result in rank orderings of research universities that are highly correlated with rank orderings from various ranking schemes.

Lombardi et al. (9) report the results of a very ambitious and interesting analysis. They compared rankings of institutions published by various sources with rankings based on a simple formula, shown in Eq. **4**:

$$BV(t) = \alpha\, NA(t) + \beta\, NC(t) + \delta\, HI(t), \quad [4]$$

where BV (t) equals the brand value at time t, and the inputs NA, NC, and HI are totaled across an institution's faculty members, drawing upon the Global Research Benchmarking System of the United Nations University's International Institute for Software Technology. They found that ranking research universities by BV produced rank orders that were very similar to those created by much more elaborate schemes.

The coefficients were all set equal to 0.333. Furthermore, we divided NA by 10 and NC by 100. This is done to assure that none of these factors, particularly NC, dominates the BV projections. Since BV is used as a measure to compare policies or scenarios, the absolute quantitative value has little meaning.

Thus, number of articles published, number of citations received, and *h*-index, totaled across all faculty members of an institution, determine BV for that institution. What about research funding, National Academy memberships, and Nobel Prizes? Our sense is these resources and awards flow to individuals and institutions with

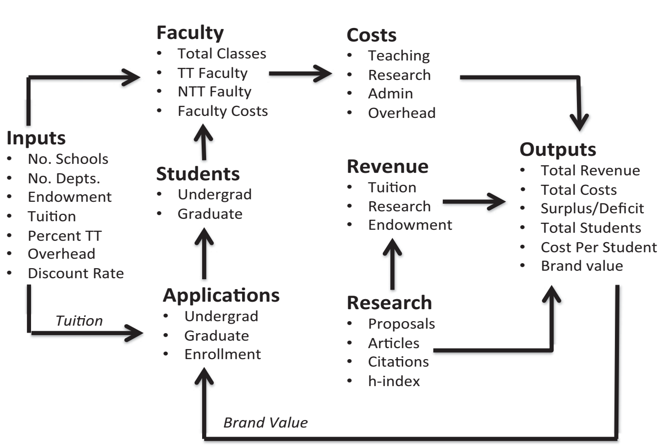

Fig. 1. Computational model of a research university. Reprinted with permission from ref. 11.

high BV. NA, NC, and HI represent the real accomplishments, as well as recognition of these accomplishments, that drive everything else at a research university, particularly for graduate programs. Nevertheless, our argument is that projections of BV are only proxies for rankings.

Revenues and Costs. Revenue in the original model came from tuition, research grants, and endowment earnings. The model was expanded for this paper to explicitly include state budgets for public universities, including projected growth rates of such budgets. Costs include those for teaching, research, administration, and overhead. Projections of revenues and costs yield model outputs that include various financial metrics, numbers of students and faculty, and brand value. Users of the model are interested in the impacts of various inputs on these model outputs. University leaders have been typically quite interested in trade-offs among percent TT, tuition, and brand value, all while trying to avoid deficits. They have quickly found that cost vs. reputation is a very central issue. As of this writing, 12 universities have requested and been provided the model described in this article. One university performed a detailed verification of the model in the process of using to address several strategic decisions. The model is available to any university that requests it.

Inputs include number of schools and departments per university, which have a strong impact on administrative costs. Endowments and tuition strongly affect revenues, as do state budgets for public universities. Overhead rates affect the portion of grants that can be used for justified general expenses rather than direct support of research. Indirect costs (IC) are costs of doing business, for example, administration, space, utilities, and training. Indirect costs returned (ICR) represent revenue, that is, the price the market pays for services. For academic grants, ICR is determined by the negotiated indirect cost rate use in proposal budgets. For academic research, prices paid are less than costs incurred, that is, ICR < IC.

The discount rate reflects the cost of money, affecting projections of the net present value (NPV) of the projected surplus/deficit (S/D). NPV, a purely financial metric, is the current value of projected future cash flows, discounted by the interest rate one must forgo or pay due to cash flows being delayed. A typical goal is to operate the institution so that NPV is driven to the point where the projected surplus or deficit is zero, that is, the institution breaks even.

Percent TT faculty has an enormous impact. Non-TT faculty members are assumed to teach twice as many classes as TT faculty members, which substantially reduces costs, especially because they are usually paid much less. TT faculty members spend half their time doing research, which may or may not be paid by research grants. The publications resulting from this research strongly impacts brand value over time.

The trade-off is very clear. Reducing percent TT lowers costs and, in principle, decreases tuition. Increasing percent TT increases costs and tuition but enhances brand value. Prospective students seek lower net tuition and higher brand value. Leaders of research universities have to decide where to position themselves relative to this trade-off.

There are many other parameters to the model beyond those shown in Fig. 1. Endowment growth and tuition growth rates are also inputs on the "dashboard" for the model. Variables embedded in "hidden" dashboards include, for example, administrative salaries and growth rate; initial number of undergraduate and graduate students; growth rates of these populations; and class sizes for both types of students. Such variables are not included on the main dashboard. Once they are set for a particular university, they are seldom varied.

There are several submodels within the overall computational model. These submodels relate to finance, administration, research, education, workforce, and brand. The research model projects proposals written, projects funded, articles submitted, and articles published. The workforce model projects decisions about hiring, promotion, tenure, and retirement. [The promotion and tenure model represents this decision as a signal detection task where the committee tries to minimize false acceptance of poorly performing candidates and false rejection of highly performing candidates (11). Of course, 5–6 y of work may be insufficient for making this discrimination (18).] The overall model and all of the submodels are explained in detail in ref. 11.

Scenarios of Future Performance

There are three forces of particular interest. They may work independently but also may have combined effects on projected results:

- S1: Competition for federal dollars and publication in top journals is steadily increasing. The current success model at most research universities requires faculty members to work harder and harder to achieve less and less success, proposal writing consuming increasing time and publication preparation receiving decreasing attention.
- S2: Foreign student applications to graduate programs have decreased in recent years due to competition from other countries and, more recently, concerns about US immigration policies. These professional master's degrees are typically "cash cows" for research universities, subsidizing many other aspects of the enterprise.
- S3: Highly polished, well-done MOOCs will increasingly succeed. Once the credentials associated with success in these online courses are acceptable to employers, it is easy to imagine a massive shift away from traditional classrooms for some categories of students, especially those seeking professional credentials and master's degrees where distance learning is already recognized and increasingly common.

We have extended and used the computational model to explore the implications of these forces for four specific research universities, two public and two private. Well-resourced universities, such as the most successful among the top 160, will likely cope in different ways. Institutions that almost totally depend on tuition dollars, which typically fall outside the top group, will struggle to keep tuition competitive while avoiding large deficits.

Using 2016 data from MUP (9), Table 3 was populated. The data in the first three columns were provided by the MUP project. The data in the remaining columns were gleaned from each university's website. We do not show the identity of each institution, but the model was explicitly fit to particular universities. Fitting the model to specific institutions was not attempted before this paper, in part due to not having the MUP data.

Fitting the model to a particular university involved the following steps:

1. Input parameters from Table 3.
2. Apply 50% discount for undergraduate tuition at private institutions or 20% for public institutions.
3. Adjust average award to match overall federal research dollars.
4. Adjust class sizes to achieve near-zero NPV of surplus/deficit; this is the break-even assumption—thus, NPV = 0 at year 0 for all scenarios.
5. Revisit steps 3 and 4 as needed.

The iterative nature of steps 3 and 4 is due to the faculty being automatically sized by the model to meet educational demands. When class sizes increase, faculty numbers decrease, fewer proposals are submitted, and fewer awards are received. This requires increasing the average award size for the university to match the overall numbers in the first column of Table 3. Note that because graduate tuition is much higher, projections are more sensitive to sizes of graduate classes.

Table 4 shows the best-fit parameters that resulted from the fitting process. Common assumptions across all institutions included undergraduate population growth rate of 3%, undergraduate tuition growth rate of 3%, graduate population growth rate of 4%,

Table 3. High-level characteristics of four research universities

University	Federal, US$M	Endowment, US$M	State, US$M	Undergraduate students	Undergraduate tuition, US$	Graduate students	Graduate tuition, US$	No. colleges	Departments per college
Large public	800	10,000	300	29,000	15,000	15,000	24,000	19	18
Large private	700	20,000	0	7,000	50,000	9,000	50,000	7	16
Small public	60	600	100	16,000	15,000	5,000	24,000	8	6
Small private	50	900	0	4,000	50,000	2,000	50,000	4	6

Note: Large and small denote resources rather than numbers of students.

graduate tuition growth rate of 5%, endowment growth rate of 6.5%, endowment earnings of 5%, and discount rate of 4%. Sensitivity analyses showed that overall results are not very sensitive to these assumptions in terms of ±1%. Negative values, in contrast, have a much larger impact.

Model Projections and Discussion

The three scenarios are succinctly defined as follows: (*i*) S1, status quo; (*ii*) S2, graduate student population declines by 5% annually; and (*iii*) S3, graduate tuition declines to $10,000 due to online offerings. The results for these three scenarios are summarized in Figs. 2 and 3. The units of Fig. 2 are millions of dollars, while the units of Fig. 3 are arbitrary and only meaningful in terms of relative comparisons.

Note that class size is varied—to 10× or 1,000—for the three instances of S3 rather than adding a fourth and fifth scenario. This reflects that fact that the external competitive driver is the same in all three cases. What differs is the institution's response to the scenario.

S3:$10K is the worst scenario, resulting in negative NPV (S/D) for everyone, because the number of students does not decrease while revenue decreases substantially. Three of the cases—S2, S3:10×, and S3:1K—lead to substantially reduced numbers of faculty, which undermines institutional publishing productivity and, hence, brand value. S3:1K is the most profitable because the number of students does not decrease but faculty numbers are cut by over 90%. Brand value, of course, plummets but only in a relative manner.

Institutions with significant resources are simply not going to let these futures happen to them. As discussed below, high-resource institutions have been the "first movers" in enabling S3:$10K. Thus, they are cannibalizing their professional master's "cash cows" before others do. They are likely to become the infrastructure platforms and perhaps content providers for resource-poor institutions. This raises the possibility that these resource-poor institutions will disappear or be absorbed by others (27).

Scenario 1: Status Quo. In this scenario, the number of proposals submitted grows exponentially, to compensate for declining success rate, which leads to number of articles submitted declining exponentially, due to lack of faculty time, which leads to a plateauing of brand value. More specifically, assuming a faculty member needs to secure an NSF award every other year, they need to submit two proposals in year 1 and seven proposals in year 20. As proposals take precedence over publications, this faculty member will submit four articles in year 1, with one being accepted, and zero in year 20, with of course none being accepted.

One might argue that just writing proposals rather than papers would hurt a faculty member's career. However, once tenured, this risk is less. Furthermore, funds from contracts and grants are needed to support graduate students and avoid large teaching loads. The intellectual work associated with proposal writing is likely to be more attractive than teaching, for example, two to three courses per semester, which can be the fate for faculty members who are judged to not be "research active."

The consequence of these dynamics is increasing subsidization of the research enterprise, which has to come from other revenues. For private institutions with small endowments, this subsidy must come from tuition revenue. This may translate into student debt, due to increasing tuitions, being used to partially fund the research enterprise. These phenomena are illustrated in detail in ref. 11.

This scenario is, of course, not sustainable. Institutions may decide to redistribute the tasks of proposal preparation and article submission to different personnel, although this may to be difficult for institutions with fewer resources. Beyond that, promotion and tenure committees might not credit the faculty with success in securing funding and publishing articles.

Universities could also help themselves by broadening their success models beyond NIH and NSF. The belief that a junior faculty member has to secure a grant from one of these agencies to gain tenure leads to their submitting large numbers of unsuccessful proposals. Intellectual outcomes are what really matter, not the source of the funds. The model for brand value considers publications, citations, and *h*-index, not sources of funding. Funding enables research, which enables publications, that lead to citations and hence *h*-indices. Universities are paying dearly, in terms of increasing subsidies, by clinging to NIH and NSF.

Shneiderman (28) discusses an approach to creatively rethinking universities' research success models. His focus on combining basic and applied research would likely enable significantly decreased costs of securing research funding. There is a risk, however, that applied research might lead to fewer articles contributing to brand value. Technical reports, for instance, are usually not well cited.

Table 4. Model parameters fit to four institutions

University	State funding growth, %	% TT faculty	Overhead rate on funded research, %	Average undergraduate class size	Average graduate class size	Average award size*
Large public	2%	70%	60%	80	28	$330,000
Large private	NA	80%	60%	16	8	$260,000
Small public	2%	30%	50%	65	45	$210,000
Small private	NA	70%	50%	40	29	$150,000

*Note that the average award is adjusted so that federal monies received matches Table 3.

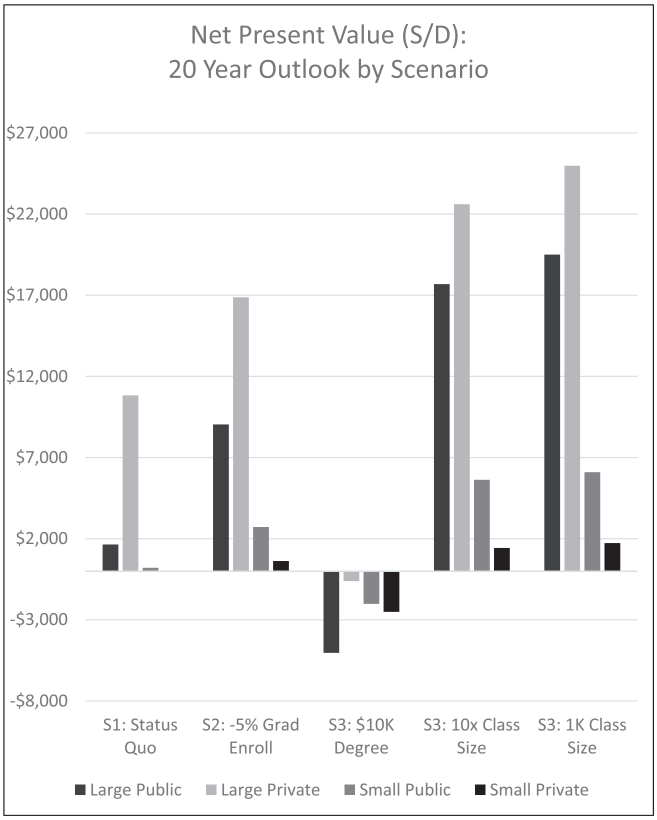

Fig. 2. NPV (S/D) for four universities and three scenarios (millions of dollars).

Beyond such changes within universities, research-sponsoring agencies could lower costs of research by changing procurement processes. For example, they could, and several do, require brief white papers with initial articulation of an idea. For ideas that have a high probability of being funded, investigators are encouraged to submit proposals. Current peer review processes at agencies such as NIH and NSF tend to reinforce reigning academic paradigms and discourage proposals outside the norm (e.g., ref. 29). These processes need to be rethought.

Scenario 2: Declining Graduate Enrollments. In this scenario, we see that declining enrollment results in declining size of faculties, which leads to fewer faculty members' research having to be subsidized, which leads to fewer publications and significantly decreased brand value. However, the key element for institutions of any size is not necessarily the total number of faculty but the number of research effective faculty, that is, the number of teaching faculty does not affect brand value.

This scenario involved 5% annual decreases of graduate enrollments, reflecting an observed trend over the past few years, as well as recent turmoil over immigration. Realistically, top players will not experience such decline, while lower players will see greater declines. The top institutions will retain their ability to pick the best foreign applicants. Fewer applicants overall will mean that the top institutions will consume a greater portion of the pool.

Scenario 3: Declining Graduate Tuitions. In this scenario, decreased graduate tuition, due to high-quality online offerings, results in substantial deficits, but brand value is sustained if class sizes are maintained at S1 levels. Deficits are highly affected by attempts to maintain the research enterprise. Graduate and postbaccalaureate certificate tuitions as a key support of tuition driven institutions and a profit center for all institutions will surely decline with the continued improvement in technology-enabled instruction, although the enhanced quality of technology can be expensive. Several contemporary initiatives have involved substantial up-front corporate investments, and subsequent enrollment of large numbers of their employees (6),

Scale here will be critical as institutions increasingly outsource the infrastructure for distance education offerings to organizations that can provide cost-effective operations. A key element in this and the other S3 alternatives will be the ability to link distance programs to high-value brands. This is an increasingly evident trend in the field as commercial providers offer institutionally branded programs on a common technology platform.

A modification of scenario 3 that captures the effects of increasing graduate class sizes by 10 times yields very positive results that differ across institutions due to baseline S1 class sizes; declining size of faculty, due to larger classes, increases surplus but erodes brand value. How much brand value will suffer as a result of changes in the scale of graduate education will depend on how key quality metrics are linked to class size.

An additional modification to scenario 3, which projects the impact of increasing graduate class sizes to 1,000 per class yields increasingly positive results, although the further decline of the size of faculty, due to yet larger classes substantially erodes brand value. A hybrid model would have such large classes for introductory courses but shrink class size to more traditional levels for advanced courses.

It is of particular note that the top institutions are driving all variations of scenario 3, with Coursera, edX, and Udacity being prime examples. These institutions have the resources to enable large experiments. They can attract major commitments from industry to underwrite these experiments and seed enrollments. AT&T and Accenture's large commitments to Georgia Tech for high-quality master of science (MS) degrees in computer science and data analytics illustrate how $10,000 MS degrees can be possible. Lower-level players, where tuitions from professional graduate degrees are their only "cash cow," are at substantial risk.

Assuming class sizes of 1,000 raises the prospect of there not being enough students to fill these classes. However, $10,000

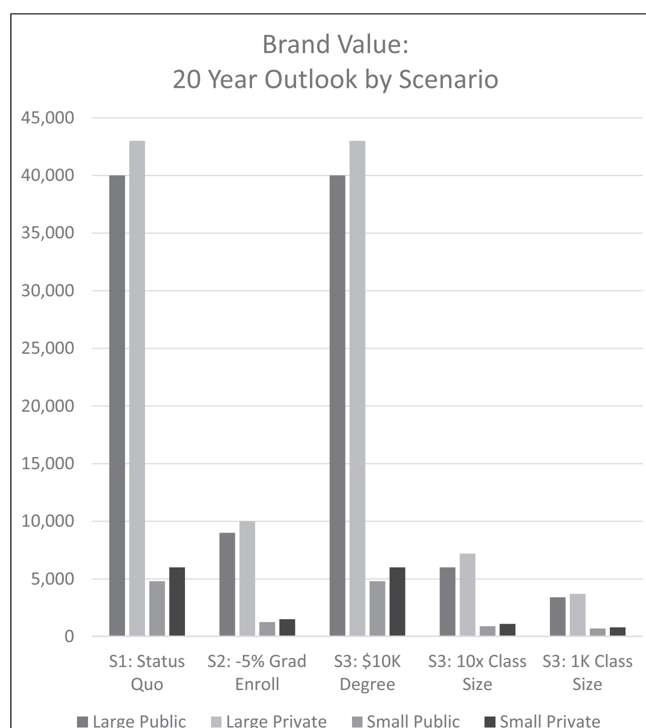

Fig. 3. Brand value at year 20 for four universities and three scenarios.

professional MS degrees are likely to spur dramatic increases in demand, in part because this price point will easily fit within many large corporations' education budgets (6). Nevertheless, the higher brand value institutions may dominate this market, to the significant detriment of the lower brand value institutions.

Overall, all these scenarios result in decreased research productivity due to diminishing returns for S1, as well as dramatically declining faculty sizes for S2 and S3. All four institutions that illustrate these scenarios benefit financially by decreasing subsidies of research, but the dramatic decrease of research output should certainly be a national concern. Using student debt, at least in part, to subsidize the research enterprise is not in the national interest. Some rethinking seems definitely warranted.

Comparing Institutions. How do the different scenarios affect the four institutions studied? Brand value decreases due to diminishing returns from research sponsors affect all institutions similarly. The ratios of brand value of large institutions to small institutions range from 4.7 to 7.7 across the scenarios. Thus, the top-ranked institutions will likely remain on top. The substantially declining research productivity of all four institutions should be a major concern in terms of economic development, national security, etc.

The change of NPV differs significantly across large and small institutions, particularly for S3:$10K. The two large institutions average NPV of −$2.8 billion, while the two small institutions average NPV of −$2.3 billion. The year 20 revenues for the large institutions average $6.8 billion, while the two small institutions average $1.0 billion. Clearly, the small institutions are not in a position to weather such losses due to the S3:$10K technology infusions transforming their graduation education business.

Conclusion

This paper presented a predictive computational model that captures key elements of the education and research enterprise to enable prediction of likely consequences of several scenarios for the future of the academic enterprise. While it is unknown what mix of these scenarios will actually emerge, universities need strategies and investments that enable robust responses to whatever mix emerges. Models such as the one extended and exemplified here, and more fully explored in ref. 11, provide institutional leaders a method of exploring the impacts of various policy decisions within their institutions, as well as assessing the impact of changes in the external environment on their institution.

Predictions for the three scenarios serve as warnings about what might happen if universities persist with their current strategies. Meyer and Zucker (30) discuss the notion of "permanently failing organizations," where persistence compensates for lack of performance. Muddling through will not work when faced with the scenarios outlined here as losing billions of dollars is not a realistic option for many institutions.

Fundamental change is in the offing. Higher education cannot sustain its current cost structures. The limits of tuition increases will inevitably be reached, significantly facilitated by increasingly powerful and sophisticated technology platforms, likely offered by institutions with high brand values. Many educational institutions will need to reconfigure their operations, restructure their financial models, or disappear amid "creative destruction" (31).

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