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Essays on PhD Output at U.S. Undergraduate Institutions

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ESSAYS ON PHD OUTPUT AT U.S. UNDERGRADUATE INSTITUTIONS

BY
ERIN NICOLE COFFMAN

A Dissertation Submitted in Partial Fulfillment
of the Requirements for the Degree
of
Doctor of Philosophy
in the
Andrew Young School of Policy Studies
of
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ACCEPTANCE

This dissertation was prepared under the direction of the candidate's Dissertation Committee. It has been approved and accepted by all members of that committee, and it has been accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Economics in the Andrew Young School of Policy Studies of Georgia State University.

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I am appreciative of the Higher Education Research Institute, the National Science Foundation, The College Board, and the Web of Knowledge for granting access to data. The use of the datasets mentioned above does not imply endorsement of the research methods or conclusions contained in this dissertation by any of the institutions listed.

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ABSTRACT

This dissertation focuses on the production of knowledge that contributes to economic growth through the accumulation of human capital and technological change. More specifically, I look at the proclivity and effectiveness of different types of universities and colleges to send individuals on to pursue a doctoral degree in science or engineering (S&E) and how PhD attainment relates to characteristics of students who attend these institutions and the faculty who teach at these institutions.

A tobit estimation is employed to test for institution effects, the effect of student and faculty characteristics, and also the impact of economic factors. To partially control for selection, survey results from the Higher Education Research Institute (HERI) are used to determine students' desire for a PhD when entering and exiting college.

I find that student and faculty characteristics matter, as do economic variables. Unobservable and/or un-measureable characteristics affecting PhD output, which differ systematically by type of institution, however, remain even after controlling for the aforementioned variables. Based on the analysis in this dissertation, I conclude that much of what are typically regarded as tier effects on PhD output are in fact due to the selective matching between students and their undergraduate institutions.

By adding measures for selective matching and proxies for individual opportunities, we see that ability, faculty characteristics and accomplishments, and peer effects maintain significant, positive effects on rates of PhD output. Finally, rates vary not only by institution type, but also by field.

Chapter I

INTRODUCTION

Human capital, the skills and knowledge possessed by workers, has been an important component of economic growth models ever since the 1776 publication of Adam Smith's *The Wealth of Nations*, in which he posited that higher levels of human capital lead to higher living standards. This idea was challenged, however, when Malthus predicted a situation where the population outgrows its ability to produce an increasingly higher level of output, leading to a decline in the standard of living. (Malthus 1798) As has been shown by centuries of increasing standards of living, his predictions were not correct.

Where did Malthus go wrong? At least one missing piece in his model was that of technology. Technology can propel society forward, allowing for increasing levels of living standards, even as the population grows. How does a society produce technological change and innovation? A primary source of innovation comes from knowledge produced at institutions of higher education. Not only do these institutions generate research, they also train the future workforce. But obtaining education - higher education, especially - involves a high investment cost upfront, as earnings are deferred until after one completes a degree.

This dissertation focuses on the acquisition of knowledge that contributes to economic growth through the accumulation of human capital and technological change.

More specifically, I look at the decision to obtain a higher degree, in particular a doctoral degree in science or engineering (S&E), as well as what types of institutions are particularly effective at outputting individuals who earn PhDs in S&E.

To begin the discussion, consider first a few facts: baccalaureate (or liberal arts) colleges produce 16 percent of total S&E PhDs among PhD earners with a known U.S. undergraduate institution. (Survey of Earned Doctorates, 1980-2008) While this is less than doctoral-granting institutions with high research activity (these schools produce nearly half at 47 percent), certain liberal arts schools produce at a much higher rate than “high research activity” universities.[1]

Joan Burrelli, Alan Rapoport, and Rolf Lehming of the National Science Foundation published an InfoBrief in 2008 that explores the issue of PhD output of science and engineering (S&E) degrees by type of institution over the years 1997-2006. They find some interesting results. First, the “Oberlin 50”, a group of fifty top liberal arts colleges, output S&E doctorates (per 100 graduates in S&E fields) at almost double the rate than any other institution group produced. These colleges had an overall average of 5-6 percent of graduates each year eventually obtaining a PhD degree. Heading the list was Harvey Mudd, 24.9% of whose graduates obtained a PhD. By way of contrast, Hampshire College (number 50 on the list of the Oberlin 50) output PhDs at a rate of 5.3 percent over the same time period. Research universities defined to have very high research activity produced the second highest average rate (2.6 to 3.1 percent), followed closely by liberal arts colleges not in the “Oberlin 50” (1.7 to 2.2 percent). Doctoral and other research universities produced at a lower rate than liberal arts

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[1] The remainder earned their bachelor’s degrees from other doctorate-granting institutions (18%) and master’s-granting institutions (17%).

colleges (0.9 to 1.6 percent). This suggests that there is something about liberal arts colleges (either the experience they provide or the process of selection) that results in their generating proportionately more PhD students.

Several other studies have looked at the issue of PhD output (referred to in some studies as production). Results of a 1998 survey conducted at the University of Delaware found that having research experience as an undergrad doubles the chance a student will complete doctoral studies. (Bauer and Bennett 2003) Another survey of 15,000 students found that about half who had earned a BA degree had participated in some sort of undergraduate research opportunity. [2] (Russell et al. 2007) Sixty-eight percent of them said the experience increased their interest in pursuing a career in the field, and the percentage interested in earning a doctoral degree jumped considerably (29% claimed a "new" expectation of earning a doctoral degree).

Robert Lemke (2008) looked exclusively at liberal arts schools (divided into four tiers based on rankings), and found the following factors to increase the PhD output rate: (1) faculty publications (positive correlation for tier 1 and 2 liberal arts schools; negative for tier 3 and 4), (2) the absence of a business school, (3) expenditures per student (only positive for tier 3 and 4), (4) enrolling a greater number of students in the top quarter of SAT scores, and (5) location: being in the northeast and a tier 1 or 2 liberal arts school creates a higher productivity rate; being in the northeast and a tier 3 or 4 generates a lower rate.

Knowing what impacts PhD output is an important policy issue. Human capital and the advancement of knowledge are extremely important for economic growth. In

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[2] All participants had earned a Bachelor's degree.

particular, science and engineering play a crucial role in this endeavor. A number of reports have expressed concern with the U.S.'s production of citizen scientists and engineers.

The National Research Council report, *Rising Above the Gathering Storm,* summarized much of this concern and listed a number of steps that the U.S. could undertake to address the issue. (2005) Not surprisingly, Congress has gotten involved in the issue. In 2006, the House of Representatives Subcommittee on Research, Committee on Science held a hearing entitled, "Undergraduate Science, Math and Engineering Education: What's Working?" in order to find out what was working and "how the Federal Government might help encourage and guide the reform…to improve learning and to attract more students to courses in those fields." (26-481PS, pg. 10) In 2007, the Senate passed the "America Competes Act." This amendment "directs the President to: (1) convene a National Science and Technology Summit to examine the health and direction of the U.S.'s science, technology, engineering and mathematics enterprises; and (2) issue a report on Summit results." The Director of the Office of Science and Technology Policy (OSTP) is also required to report annually to Congress with "recommendations for areas of investment for federal research and technology programs." (United States Senate, S.761)

Why else might increases in funding be important to the growth of science and engineering? Work by Richard Freeman has shown that one effective way to increase the number of students going to graduate school is to increase fellowships. According to Freeman, "the costs of spending money for stipend payments in order to increase the supply of quality researchers are minute compared to other government expenditures, yet the benefits are potentially enormous for the economic and research agenda." (Freeman et al. 2005) Freeman and his coauthors find that a ten percent increase in the number of stipends awarded results in a 41 percent increase in the number of applicants and a 7 to 15 percent increase in graduate school enrollment overall.[3] He also finds the larger the share NSF graduate student grants are of GDP, the higher the enrollment in undergraduate science and engineering majors. (2006)

President Obama's science advisory team understands this. In his first radio address to the nation in 2009, he called for a tripling of science fellowship grants (including NSF and NIH grant programs) for undergraduate and graduate students. (Bhattacharjee 2009) He also called for a doubling of funds for science research in the next five to ten years. His plan would have given NSF $550 million more (an eight percent increase) in 2010 than it received in 2009. "The funding expansion for science supports a belief long held by Obama that jobs of the future will come from industries like clean energy that are driven by scientific and technological breakthroughs." (Garber 2010)

President Obama's initial plan was not implemented; with the state of the economy, budget cuts and other needs won out over science funding. However, in his 2013 budget proposal, he re-introduced an emphasis on S&E education, proposing an increase in funding for science and math education. The goal of this line item (which reflects a five percent increase over 2012 funding) is to train new teachers for math and science, who the President claims would help "meet an ambitious goal, which is 1

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[3] Another result is that the level of stipends also matters in addition to the number awarded. Freeman et al. recommend increasing stipend levels from $30,000 per year to $40,000 per year. (2005)

million more American graduates in science, technology, engineering, and math over the next 10 years."[4]

As can be seen, the production of scientists and engineers is an important policy issue. This dissertation addresses numerous questions surrounding this topic. What is the production function (for PhD degrees) of undergraduate institutions? How does the output of PhD students from liberal arts schools differ from that of research universities and within the liberal arts institutions how does it vary? How does selection affect the results? Are certain schools particularly good at attracting students committed to graduate school, while certain other institutions are particularly adept at “producing” graduate student?

While several studies have looked at similar issues, several unanswered questions remain. First, is the question of selection. There are two somewhat related aspects: ability and whether the institution selects individuals who already have a strong commitment to graduate school. Second, while top liberal arts colleges and top research universities have been studied, lower tier schools have not been looked at in depth. This dissertation explores both of these issues.

The second chapter of this dissertation explores the economics of higher education institutions, including objective and production functions and how to model each. Differences between typical production models and higher education-specific production models are discussed. The specific objective of PhD output is introduced into the general model.

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[4] Reiny 2012

The third chapter models the decision to get a PhD from the student's perspective. What factors increase the probability that one will pursue science and engineering? What factors increase a student's desire to pursue a PhD in S&E? What role does the undergraduate institution play in these deciding factors? These questions are addressed.

The fourth chapter builds an empirical model to estimate PhD output using four large datasets: the Survey of Earned Doctorates, Thompson Scientific Web of Knowledge (a database of journal publications), The College Board, and The Freshman and Senior Surveys from the Higher Education Research Institute at UCLA. I estimate productivity with a Tobit model, and test the impact of institution, faculty, student and economic variables on PhD output.

Finally, Chapter 5 considers results from Chapter 4 and the resulting policy implications. What can a university do to increase their rate of PhD output? What are the costs? What can government or industry do to increase incentives that will result in high S&E PhD output?

Chapter II

THE PRODUCTION AND OBJECTIVE FUNCTIONS OF U.S. UNDERGRADUATE INSTITUTIONS

Introduction

In studying an organization, economists typically begin by defining the objective function of the organization and the means and constraints available to the organization for achieving the objective. For example, it is typically assumed that the goal of a firm is to maximize profits from producing a product sold in the market. The various ways the firm can produce the product are mathematically modeled in the production function. The firm chooses the technology and input mix that minimizes cost, and that choice depends upon the relative price of inputs. In order to maximize profits, the firm sells a quantity where marginal cost equals marginal revenue. By operating in a for-profit world, the firm is then able to distribute the profits among owners of the firm. Competition forces long-run profits to reflect opportunity costs and weeds out inefficient firms.

By way of example, a baker needs inputs of flour, water, yeast, an oven, and labor to make bread. When the production function is established, the bakery can use it along with the cost of inputs to determine the lowest cost of producing bread of varying quantities. There is a fixed ratio of some inputs (i.e., there is a given ratio of flour to water to yeast), but the optimal combination of some inputs (e.g., labor and equipment) depends upon the price of the inputs. This can lead to a variety of production paths depending upon the relative cost of inputs. The baker then chooses to produce a quantity where marginal cost equals marginal revenue. One reason describing the production of bread is straightforward is that the output and the market are reasonably well defined.

To extend this framework to institutions of higher education, I first consider the similarities and differences between education and other organizations usually studied by economists.[5] Schools all sell products (such as a BA education), use inputs, purchase these in a market (e.g., faculty and buildings), and are subject to technological change. Various ways to produce the products are represented in the production function. However, there are many differences from the typical firm model, and the study of institutions of higher education presents numerous challenges.

First, institutions of higher education operate in the nonprofit world, which functions differently from the typical for-profit world (as summarized in the simple example of the bakery above). Second, in some instances, outputs are the same as inputs (e.g., students). Third, the market is not concrete, because education is an experience good, which means quality cannot be evaluated prior to purchase – only after consumption can one assign a true value to the product. Finally, there are generally not one but multiple objectives, such as quality education of students and reputation. There are also multiple products, such as research production and number of graduates per year. All of these issues in turn relate to the type of institution, as

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[5] For a closely related discussion, see Winston (1999).

objectives and desired product(s) vary greatly across institutions. We do not, for example, expect a liberal arts college to have the same goals as a Research I university and, therefore, we cannot expect them to behave in the same manner.

Indeed, institutions of higher education operate differently than a one-product, for-profit private firm. In what follows, I briefly discuss the differences mentioned above, the objectives of higher education institutions, the production function for achieving these objectives, and how these issues differ between types of schools. I will discuss the questions of what higher education institutions want to maximize and how the outcome is measured. Also discussed will be PhD output, which I define as the percentage of graduates from an undergraduate institution who eventually obtain a PhD. My focus will be on the role of institutions in producing these subsequent graduate students, specifically in the areas of math, science and engineering.

Nonprofit Operations

With rare exception, institutions of higher education function in the nonprofit world. Nonprofits vary from the typical model of the firm in a several ways: (1) excess income cannot be distributed among owners, (2) receipts are often lower than costs and thus nonprofits must rely on donative resources, (3) nonprofits may be led by stakeholders with different objectives than those in a profit-maximizing world, and (4) nonprofits may not employ resources efficiently. These variations are expanded upon below.

The very definition of a nonprofit is that it operates under a non-distributive constraint (Hausmann 1990), meaning that a non-profit cannot distribute excess income (i.e., profit) among stakeholders. While the presence of a non-distribution constraint exists, institutions may find other ways to distribute excess funds (e.g., stipends for graduate students, greater fringe benefits for administrators, etc.). In addition to the distribution constraint, nonprofit status means that the organizations are exempt from taxes, which changes the relative prices as compared to those faced by a for-profit firm.

Many nonprofits are unique in that they take in less than they spend. Higher education institutions are no different - student tuition payments do not typically cover the cost of operation, meaning their product is sold below cost (i.e., they choose to market their product at an average price that is below average cost).[6] How do these nonprofit firms continue to function? They do so because nonprofits have donors, and thus their receipts need not equal their cost. This difference is made up through what Winston calls donative resources – donations, charitable giving, and, for some institutions, government support. (Winston 1999) However, nonprofit status does not mean that all institutions are hurting for funding – only that they must rely on donative resources.

The input of donative resources means nonprofit organizations must be cognizant of external stakeholders, although these external stakeholders (alumni, the board of trustees, and community leaders, in the case of higher education) cannot significantly impact operating costs on a day-to-day basis. For private institutions, those that can exert considerable influence in the distribution of funding are generally internal (administrators, faculty, and students). For public institutions, legislatures and state agencies have a great effect on funding and operations. Institutions of higher education

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[6] In almost all cases, the price paid by the student is not the sticker price – this price, if paid, would cover costs.

must also be responsible to these internal stakeholders, and must balance decisions between the desires of all stakeholders.

The competing interests of stakeholders can lead to a lack of efficiency. Ehrenberg (1999) discusses this issue related to college deans at Cornell University, which he believes to be representative of a "typical" university.[7] He argues that a dean is typically concerned with her college's funding and development, and does not place the institution's overall goals above her own college. Because of the nature of her job, she has strong support among her college's stakeholders, from donors to alumni. These stakeholders are most influential; often the president and provost's goals are of secondary importance, and the institution fails to maximize its objectives as a whole, or at least the objectives of the central administration.

Additionally, nonprofits may not employ resources efficiently. By way of example, an article in the *Chronicle of Higher Education* by Siegfried et al. (1995) discussed a survey of 200 schools regarding the implementation of 30 different types of innovations, ranging from automated library catalogs to courses in women's studies. They found that the average time from the first school implementing an innovation to more than half obtaining the innovation was around 25 years, over twice the amount of time firms in the private industry usually take to adopt new innovations.[8] The authors attribute this to the reactive nature of the administration, and the absence of direct involvement from the board of trustees.

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[7] He notes that most liberal arts colleges operate under a centralized budget system, which is more in line with a basic utility maximizing model. For institutions with more complex budgeting systems (and for those with decentralized budget management), he argues the basic utility-maximizing approach is not truly representative.

[8] As the authors mention, this is not surprising when considering regional public universities, as they are less competitive because of a 'guarantee' of students from the state/region. However, the authors note as unexpected the lack of innovation from selective liberal arts colleges and private research universities.

Ehrenberg (1999, p. 104) notes the lack of efficiency at Cornell University due to not considering relative prices between fields. In a typical firm, changing relative prices alters the choice of output. At Cornell, this is not the case. Historically a science and engineering powerhouse, Cornell has seen its costs rise as federal funds for indirect costs for science have fallen and startup costs for new faculty have risen. Ehrenberg argues that the efficient solution for production would be to substitute away from those inputs that are high in cost relative to those which are more affordable.

Outputs as Inputs

Institutions of higher education are unusual in that their product not only depends on the input mix for production, but the inputs *are* the product in some cases. Winston calls this "customer-input technology," referring to the fact that peer effects greatly matter for an institution's output. (Winston 1999) Clotfelter (1999) also discusses inputs as outputs: "the 'customer's' own effort and the quality of fellow students" complicates the assessment of output. He also identifies two complementary outputs – student learning and faculty research – both affected by inputs (student and faculty ability and effort[9]).

Winston and Zimmerman (2004) examined peer effects by analysis of the ability of a student's roommate, who is randomly assigned by the college. Using SAT scores and grades from Williams College undergraduate students, they find "students in the middle of the SAT distribution do somewhat worse in terms of grades if they share a room with a student who is in the bottom 15 percent of the SAT distribution." Students

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[9] He notes also the importance (historically) of physical proximity, and questions the ability of online institutions to provide a typical "college" experience. This is another reason I will focus primarily on institutions providing more traditional education experiences.

scoring in the top SAT distribution are not typically affected by the SAT scores of their roommates, whether relatively high or relatively low.

Todd and Ralph Stinebrickner (2006) research peer effects at Berea College through randomly-assigned roommates. The authors note previous studies by Sacerdote (2001) and Zimmerman (2003), which found little presence of positive peer-effects. However, they believe this could be because of the lack of low-ability students at the institutions studied (Dartmouth College and Williams College). Berea College, on the other hand, has a large population of economically disadvantaged students as well as lower than average SAT/ACT decile scores. The authors find females with high-performing roommates (as based on high school GPA – not test scores) earn better grades with regard to first year performance (without the high-performing students incurring a ‘cost’). Male students show no effect, which could be explained by the amount of time male students spend with their roommate compared to female students (the authors note females spend 20% more time with their roommates). The data support their hypothesis that, at least for female students, previous studies may not have found peer effects because of a relatively homogeneous student population.

Similar to the students, peer effects also exist when it comes to faculty. For example, the research productivity of a faculty member relates in part to the productivity of her colleagues (Stephan 2012). We can think of an example of a one or two person department (e.g., at a small liberal arts college) versus a thirty-person department; opportunities for collaboration are greater, and the cost of finding a collaborator is lower, in a large department.

Ignoring faculty peer effects, faculty ability and effort will produce a higher output of research, all else held constant. Input costs reflect this (i.e., salaries vary based on a faculty member's education, level and quality of institution; and prior and expected research record). Institutions may buy 'trophy' professors (e.g., those who have won prestigious awards, are members of the National Academies, or have high numbers of citations) in an effort to raise their reputation.

Likewise, even if one ignores student peer effects, a stronger input of student ability and motivation will produce a higher output of student achievement in higher education. These students raise reputation through their incoming "statistics" (e.g., SAT scores, class rank, etc.) and therefore increase competitiveness and perceived quality of an institution.[10] Stronger students are paid for their contribution to production and reputation: "strong students pay a lower net tuition than weak ones because they contribute more on the margin to the educational activities of the university and hence get more financial aid." (Winston, 1999) The same can also be said for the students earning athletic scholarships or those contributing to teaching or research as assistants, as all of the above are supporting one or more of the institution's objectives. In a similar manner, students with strong preferences to attend graduate school can raise the reputation profile of the institution.

Experience Goods

Many firms produce inspection goods (sometimes referred to as search goods), the quality of which can be easily judged by the consumer. These goods are subject to price competition and substitution of other goods. For example, a consumer can shop

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[10] However, measuring a flow of output for particular students is much more difficult than for a member of the faculty (who can be followed through their production of a flow of research output).

for a refrigerator and, using information based on reputation and comparative goods, can choose a product she can be reasonably sure of with regards to quality and expectations. Search goods present consumers the opportunity to invest time in research and be rewarded with more certainty.

However, not all firms produce goods of this nature: restaurants, sporting events, and books all are examples of what can be thought of as experience goods - goods that cannot be simply assigned a value by the consumer ex ante. Of course, reviews of restaurants, team reputation and book reviews are sources of information, but the nature of the good is a more personal experience than that of a refrigerator, for example. Many of these types of experience goods are chosen for consumption using a trial and error method, and this works because of the low investment cost required.

The investment cost of a good can affect the demand for that good. For example, Bryson et al. (2005) examine the demand for unionization amongst differing age groups and try to identify why unionization rates are lower for younger workers. The authors identify unionization as an experience good, as the benefits of union membership cannot be fully assessed until after joining. Bryson et al. describe the investment cost of joining as decreasing as age rises, which causes lower demand for unions at younger ages.

Higher education is also an experience good, although McPherson and Winston (1993) argue that because of its cost, a consumer is understandably hesitant to use the same trial and error approach in consumption. For example, one must enroll and actually attend in order to assess the quality. For this reason, purchasers of education are required to make assumptions of quality, based on indicators rather than measures of true quality. One doesn’t know the true quality until after the purchase – when the experience is occurring. “People investing in human capital through a purchase of higher education don't know what they're buying—and won't and can't know what they have bought until it is far too late to do anything about it.” (Winston 1999) Relatedly, “Studies of consumer satisfaction suggest that consumers are more likely to ‘learn to like what they buy’ than ‘buy what they like’, especially if they purchase an experience good.” (Bryson et al. 2005) Moreover, because customers vary in taste, the same education can be evaluated as producing a different quality across customers. Because of this, consumers of higher education (students and parents) put more emphasis on reputation measures of an institution, which can cause these institutions to focus on factors that increase reputation.

Multiple Objectives and Multiple Products

The objectives, or goals, of an institution are multiple in number and vary by institution type. Many papers have tried to summarize (or even model) the objective function – a mathematical representation of the institution’s goals. As an early example of identifying goals, Abraham Flexner (1930) discussed the role of higher education as encompassing four main objectives: “the conservation of knowledge and ideas; the interpretation of knowledge and ideas; the search for truth; the training of students who will practise and ‘carry on.’”

In many instances, as in the example above, the objective of an institution is intangible and therefore difficult to measure. Clotfelter (1999) discusses the “pursuit of excellence” as a common objective of the higher education institution. This describes the constant reaching for increasing quality in production, given the same resources as another institution. This can also be thought of as increasing perceived quality *relative* to others in the market (e.g., achieving higher rankings than in previous years). Indeed, excellence is often measured relative to others, and often the relative position of an institution drives the objectives of the stakeholders. In other words, objectives are formed based on competition within a niche of the higher education market; institutions do not generally compete with all other institutions, but with those of similar purpose and resources. Ehrenberg (1999) points out that market niches are partly attributed to the number of stakeholders an institution has; compared to large research universities, liberal arts colleges have relatively fewer stakeholders to answer to. This segments institutions into types and tiers with institutions essentially competing against those in their niche.

Multiple Objectives

Considering educational institutions as firms, each school wants to produce a product that caters to its customers. Customers, in the case of higher education, are typically thought of as students and their parents. However, as noted above, there are many other stakeholders to whom higher education institutions must answer: alumni, donors, community leaders and politicians, athletic program boosters, and, in the case of faith-based universities, religious institutions. Because these stakeholders have somewhat different ideas and values regarding the objectives of higher education, these institutions must carefully weigh the goals and the outcomes they produce.

Defining “the institution” (i.e., the sum of all stakeholders) is important when thinking about the objective and outputs of educational institutions. Certainly the president, the deans, and the faculty all have differing opinions of the institution’s goals.

As Ortmann (1997) explains, in discussing the differing objectives of stakeholders and the relation to maximizing objectives, “complicating matters is the high degree of autonomy that faculty is often granted and its non-hierarchical organization. Organizational outcomes are thus also functions of cognitive patterns of faculty.”

Within an institution’s overarching goals, there are sub-goals, some of which align together, others of which diverge. The values of an institution (i.e., the collective interest of stakeholders) ultimately determine the objectives. Garvin (1980) modeled a variation of this by aggregating department-level utility functions to obtain a utility function for the entire institution. However, his model assumed all departments were seeking to maximize prestige, which is one objective for all (however, the manifestation of the utility-maximizing behavior could vary).

Almost all stakeholders are interested in achieving (or maintaining) high rankings (i.e., reputation), which is related to the goals mentioned above. Rankings “are a sign of the times…their very existence and undoubtable impact on decision making at colleges and universities lays the foundation for widespread reputational enforcement.” (Ortmann 1997) Current ranking systems (e.g., *U.S. News and World Report*) try to quantify the outputs mentioned above using various measures. Research is measured by grants, publications, citations, patents and lab space. Teaching is measured by student satisfaction, percent of faculty with PhDs, and graduation rates. Overall satisfaction among students, parents and alumni are measured in part by donations (both by participation of giving and amount).

For schools where stakeholders value student experiences highly, emphasis is placed on teaching faculty, extracurricular facilities and other students. For schools where research is the priority of the stakeholders, emphasis is given to facilities, equipment and the quality of research faculty. Thus objectives vary across (and between) tiers and types of institutions, and this is manifested through the production of different ‘products.’

The Higher Education Institution’s Objective Function

As mentioned above, the educational institution has several goals: to educate students well, to produce quality research, to attract high-achieving faculty and students (also considered inputs), to provide a rich student experience, and to maintain high retention and alumni donation rates, among many others.

Examples from the Literature

Modeling the goals and production of these institutions can be difficult. According to Rothschild and White (1993), “the goals of some members of the university community (faculty and students) are perhaps not too difficult to model, but the motivations of others (in particular, senior administrators, regents, and trustees) resist easy characterization." Because of this, multiple approaches have been taken in modeling the objectives of higher education institutions.

Geraint Johnes (1992) modeled a two-party system of higher education, incorporating the principal (government, funder of higher education) and agent (the higher education institution).[11] The government funds multiple agents in its jurisdiction. In this model, the principal’s objective is to maximize value added by the institution to society, while the agent’s objective is to maximize prestige. Value added to society is

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[11] Johnes’ research focuses on the UK, where institutions are public, so the application to private US institutions is not transferrable.

measured through student drop-out rates, degree completion rates, and research produced by professors (both in quantity and quality). Johnes concludes that the principal (i.e., the government), in order to maximize its objective function, would identify the least productive institutions and seek to raise the value added at these schools. However, a problem lies in the ability to identify efficiency, which requires a measure of prices for inputs and outputs, many of which do not exist in the market for higher education. (p. 32)

Ortmann and Squire (1999) take a game theory approach to modeling higher education objectives and production in an attempt to explain the rising costs of higher education throughout the 1980s and 1990s. While their approach is very simplified, it can lend insight into the manifestation of different objectives of different institutional roles. They assign three types of stakeholders within the institution: Overseer, Administrator and Professor, each impacting production through actions taken based on individual goals. The Professor has three main objectives: to have free use of his time, job security, and maximization of income and reputation. According to the authors, tenure is the best path to achieving these goals, and tenure most often is awarded on the basis of research accomplishments.[12] This leads the professor to choose research over teaching and other administrative duties, which increase administrative costs for the institution.

The Administrator has four main objectives, three of them are the same as the three of the Professor, but manifested in different ways. The fourth is to achieve status and power, “manifested in a large office and support staff.” (p. 7) In order to maintain job

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[12] This is a very simplistic approach, especially when considering private institutions. For a detailed discussion of tenure and the related literature, see McPherson and Schapiro (1999).

security, the Administrator must keep the Overseer happy, which comes by improving the school's reputation. In terms of delegating management duties, the Administrator's best response is to hire more staff, as she will both increase her power and status by managing a larger staff as well as avoid conflict with the Professor, who is attempting to avoid such duties.

Finally, the Overseer (defined as the alumni and students of the institution) has one goal: to enhance the reputation for educational quality at the institution.[13] The Overseer is compared to a shareholder of a stock, but without access to quarterly performance measures. Therefore, the Overseer must rely on (at a much slower-paced) student selectivity statistics and outcomes. This results in a great deal of trust placed in the Administration for decisions regarding budget, management and hiring, and realization of mismanagement is slow to occur. All of this leads to asymmetric information, an increase in budget share allocated towards administrative costs, and increased cost per student educated. Once an institution clarifies its objectives, it then determines the output it wishes to produce in order to achieve its goals.

Objective Function and Product Choice: Higher Education Institutions

As mentioned above, institutions of higher education produce multiple products, which are chosen based on their objectives. A necessary endeavor in maximizing the institution's objective function is for the schools to decide the mix of products they will produce. Because not all stakeholders (i.e., professor, administrator and overseer) have the same objective function, the production within an institution is affected - both in

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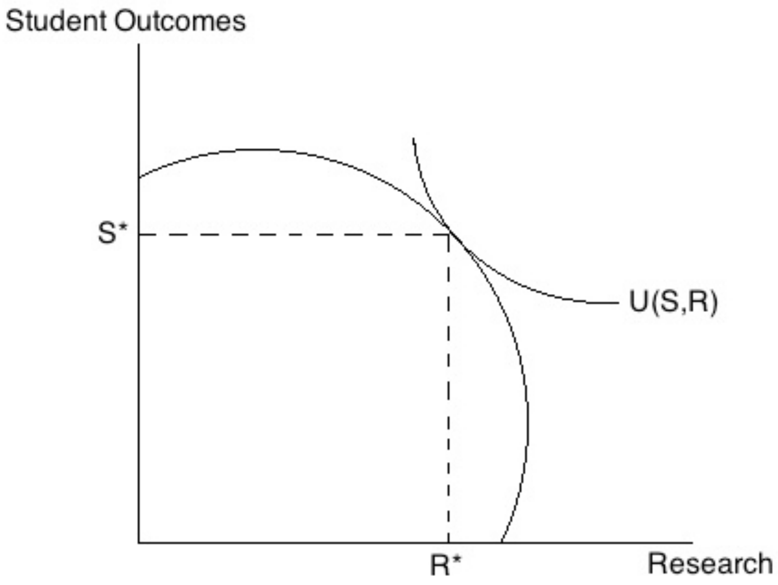
[13] This assumption ignores the case discussed above of outside stakeholders (e.g., sports fans, legislators, etc.).

output and how that output is produced - by the varying goals of the stakeholders and by their ability to influence outcomes.

Consider a production possibilities frontier. In the basic model, the frontier illustrates what combination of two products can be produced, given the efficient use of resources costing a specified amount. The two products in this example are student outcomes (i.e., teaching) and research (Figure 2.1 below illustrates). The chosen mix of output occurs where the utility function (i.e., the objective function) is tangent to the production possibilities frontier. Note the upward slope close to the axes; this shows that virtually all institutions have some research and some teaching – an indication that they are strong complements.

Figure 2.1: Production Possibilities Frontier



The institution’s chosen output level (in the case above it is [S*,R*]) depends upon the ability to produce a combination of goods as well as the objectives of the institution. Changes in input prices, changes in technology, and changes in resources will change the frontier; the level of utility will expand or contract accordingly, creating a new combination of products. This analysis can be expanded to include more than just two outputs.

Because many goals are relative and intangible, the institution's objective function is not easily defined. While it is relatively simple to list an organization's goals, representing them in a mathematical form is much more difficult, especially when the objectives are not easily measured. Institutions may choose to measure achievement of objectives through certain outputs. Measuring this output, however, is also not easy. This issue is discussed in the next section.

Measuring Output

The measure of objectives through output is a complicated issue, and one that institutions and other researchers have tackled in various ways. Consider student learning, for example. Swarthmore measures student achievement by using outside faculty to grade written and oral examinations. In another example, a project funded by the U.S. Department of Education places similar institutions (close in geographic location) into groups of three so that they may 'trade' faculty (for both facilitation and assessment) and increase uniformity across schools. (McPherson et al. 1993)

Hopkins (1990) presents a thorough discussion of the measurement problem in identifying a production function of higher education institutions, and even admits it is likely impossible to identify a correct specification. The following table, taken from his work, indicates the main obstacle encountered in modeling higher education production: intangible inputs and outputs. To be a bit more specific, intangible variables are the true measure of what we want to capture, while the tangible variables are the best available proxy for the intangible measurement.

TABLE 2.1: Identification of Inputs and Outputs in Higher Education

	Tangible	***Intangible***
Inputs	New students matriculating	Quality & diversity of matriculating students
	Faculty time & effort	Quality of effort put forth by faculty
	Student time & effort	Quality of effort put forth by students
	Staff time & effort	Quality of effort put forth by staff
	Buildings & equipment	Quality, age & style of buildings; age & quality of equipment
	Library holdings & acquisitions	Quality of library holdings and acquisitions
	Endowment assets	
Output	Student enrollment in courses	Quality of education obtained
	Degrees awarded	Quality of education obtained
	Research awards, articles & citations	Quality of research performed (also quantity)
	Services rendered to the general public	Quality of services rendered
		Goodwill & Reputation

Source: The Higher Education Production Function: Theoretical Foundations and Empirical Findings (Hopkins 1990), in The Economics of American Universities: Management, Operations and Fiscal Environment (Hoenack and Collins, eds. 1990)

There are many definitions of student achievement that are not easily measured, such as “leadership potential, moral integrity, and the ability to respond to new ideas.” (Schapiro 1993) Many schools conduct their own surveys (e.g., University of Tennessee, Alverno College and Northeast Missouri State University), and although these measures change over time, the results are not comparable across institutions. Various surveys from Educational Testing Services (ETS), the American College Testing Program (ACT), and the National Center for Higher Education Management Systems (NCHEMS) attempt to collect such information by polling current and former students, although the issue of comparability across schools remains, especially if pre-surveys are not given. (McPherson 1993)

Research is another form of output that is typically measured. Measures can include the amount of grant funding, publications (quantity and quality), citations, and patents. While research is measured separately from student learning outcomes, Schapiro (1993) rightly points out that ideally one would want a measure of the interaction of the two. This would be especially helpful in identifying graduate student productivity (i.e., the propensity for an institution to send students to graduate school).

While many of these intangible inputs and outputs continue to be used, there have been great strides in measuring a number of these variables. The College Board, for instance, provides datasets on entering classes for almost every higher education institution in the country. These data include information on student quality (through standardized test scores and graduating class percentiles) and diversity (by income, race and ethnicity). Publication quantity and quality have been measured as well.

To summarize thus far, we have looked at how higher education institutions vary from the typical for-profit firm, how these institutions form objectives, and how these objectives lead to a choice of outputs. Once the output mix is chosen, institutions must decide how they will produce their products. The next section outlines this decision process.

Multiple Products

Just as there are multiple objectives, there are multiple products (i.e., outputs). Institutions of higher education can thus be thought of as multi-product firms, each producing (to a certain extent) products including education, student experience, publications, patents, and community involvement/contributions. Many studies of the functions of the higher education institution focus simply on teaching and research, arguing that most output can be classified as one or the other. Teaching can include student outcomes, graduate satisfaction, and job placement rates, among others. Research can include grants, publications, and patents, among others. As mentioned above, objectives define the type of institution and the products it produces.

Consider first a liberal arts college. By definition, the college's objective is to focus on the undergraduate years, and therefore it sees offering a high-quality undergraduate education and student experience as a top priority. These colleges promote interaction and support between all levels of the school, provide large amounts of funding for promoting student activities and extracurriculars (such as study abroad), and invest in state-of-the art dormitories and workout facilities.

The role of faculty in the institution is certainly different from Flexner's view of the role of professors: "the university professor has an entirely objective responsibility-a responsibility to learning, to his subject, and not a psychological or paternal responsibility for his students." (1930) Students attending liberal arts colleges expect to have close (and supportive) interactions with their professors. Therefore, liberal arts colleges prefer to hire PhDs who will put teaching first. Because of this, students attending a liberal arts college have greater exposure to their professors, some of who conduct their own research projects. Liberal arts colleges may also provide off campus research experiences – either in the summer or semesters at a research facility. Those in close proximity to a research university may also have joint programs that foster student research experiences.

Next, consider the large research university, such as University of Wisconsin - Madison or University of Texas-Austin. These universities are focused on reputation, research production and funding. Unlike the small liberal arts college, reputation is not based primarily on student experience, education and outcomes, but on research attainments, both in funding and in publications. The product of interest is research, but - unlike the liberal arts college – undergraduate students may be less exposed to this first-hand. Students at large research institutions often have graduate students as instructors and less one-on-one time doing research with faculty members. While research is more prevalent, undergraduates experience this research most likely through working with graduate students, not full time faculty. Even those who work in a professor's lab often "report" to a graduate student or a postdoc.

Other types of institutions are also of interest: lower-tier liberal arts colleges, mid-ranked public universities, and faith-based institutions, all of which will be explored in this study. Of course, within the realm of each of these categories there are multiple 'tiers' of school quality, ranging from the very elite and selective institutions to top-tier religious institutions to lower-ranked colleges. The output at these colleges certainly differs.[14] The inputs (particularly the inputs of other students and the faculty) are the driving force behind quality of the products; these inputs are discussed in a later section of the chapter.

We note, before continuing the discussion, that although a small part of the higher education community, the for-profit university is an expanding portion of the higher education market. These schools can be viewed as being closer to the typical firm, as they have the goal of maximizing profits. However, these types of institutions produce very few PhDs. They also often engage in distance learning, which minimizes

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[14] In addition, within any given institution, the outputs vary considerably across – and to a lesser extent within – departments.

peer effects. Because of these differences, and given that most of these institutions have a short history (and little available data), for-profit institutions are not discussed in much detail and are excluded from this study.

The Production Functions of Higher Education Institutions

A production function models how inputs are used to create output(s). The simple model presents two inputs and a budget constraint; the firm chooses to use a combination of inputs where the relative prices of inputs equals the ratio of the marginal products. It produces an output where the marginal cost is approximately equal to the marginal revenue. The application of this to institutions of higher education is complicated by the issues discussed above: their nonprofit status, the production of multiple products, the nature of the output they produce, and the fact that some of the inputs are also outputs. The next section summarizes how previous research has approached production in higher education institutions.

Examples from the Literature

Johnes (1992) describes a value-added production function, and he uses data from Great Britain. Output is measured by proxies of ‘performance indicators’ (degree quality, student attrition and research performance), input is measured by student quality upon college entry. Degree quality is measured by a test score coefficient that is derived from a regression. The regression’s dependent variable is the percentage of students graduating with top honors (first or second level), and independent variables are the above-mentioned test scores, degree type, percentage living at home, type of institution (e.g., by field such as technology and also by age of school), and library expenditures.

Johnes chooses to use student attrition as a measure of output because it provides a measure of “wasted inputs.” He measures attrition rates both for all those entering a university or college program (attrition measured by those who graduate), and for those continuing for at least one year (i.e., freshman attrition rate). Research is measured by citation analysis, publication analysis and peer review.[15] His self-admitted flaw in the analysis is the use of output measures instead of his intended value added. He explains: “Indeed, a high score on output measures could plausibly reflect obesity. Leaner and fitter institutions may exist which - although they produce relatively little output - consume fewer resources per unit of output.”

Perhaps more in line with the way higher education institutions operate, is the multi-production function that Cohn et al. (1989) estimate, which measures teaching by number of full-time enrolled students (a separate measure is used for both graduate and undergraduate education) and research by the amount of grant money received by the institution. Their study includes only one factor price: faculty salaries, including fringe benefits. The authors investigate the presence of economies of scale and economies of scope (when complementarities from production arise). One of the findings is that higher education institutions may be able to lower cost by increasing size, but only if growth is experienced in both teaching and research. In other words, growing research capabilities at a university without also increasing enrollment does not increase efficiency. They also find the more broadly-focused universities (including enrolling undergraduate and graduate students as well as taking on research) are more efficient

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[15] This is a measure used in a few studies in the UK (for UK institutions). Peer review is defined as “a group of nominated experts meets to agree on a ranking of departments based on their own subjective opinions.” (pg. 31)

than institutions focused on only one or two of the products (i.e., undergraduate teaching, graduate teaching and research).

There are a number of issues with the methods used by Cohn et al.. First, the number of enrolled students is not the most appropriate measure for the output of teaching. Teaching would be better measured as some form of quality (as opposed to simply quantity), ideally by some measure of student outcomes (e.g., value added test scores). Measuring research by grant funding could also be improved, perhaps by including publications and citations instead of grant funding, which is primarily an input.[16] Second, the only input price measured was that of faculty salaries. As mentioned above, educational institutions not only have multiple outputs, but multiple inputs as well. Finally, while the paper did separate out private versus public sector institutions, the schools could have been further divided by tier and type.

Modeling the Production Function of Higher Education Institutions

As discussed above, the production function uses a set of inputs to create the desired output. Institutions have similar inputs across types of institution, although the volume, share, and quality that they choose differs. All institutions can “shop” at the same “store” (e.g., for faculty, facilities, funding, etc.), but the production function and relative input prices will determine the choice mix of inputs for production.

Inputs include faculty (of all sorts - researchers, clinical professors, lecturers), facilities for research and teaching, equipment, extracurricular facilities (these can play a major role in the production of “country club” like settings at many liberal arts colleges). Other inputs include students who are important to production because of

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[16] Grant funding also varies greatly depending on the type of research and field.

spillover or peer effects. Each of the inputs can be defined and measured based on the objectives (including sub-goals) of the institution. The input mix will also vary between institutions, based not only on differing objectives but also because they may face different relative prices for inputs. Once the optimal product mix has been determined (as illustrated above in Figure 1), how to produce each of these products is the next consideration.

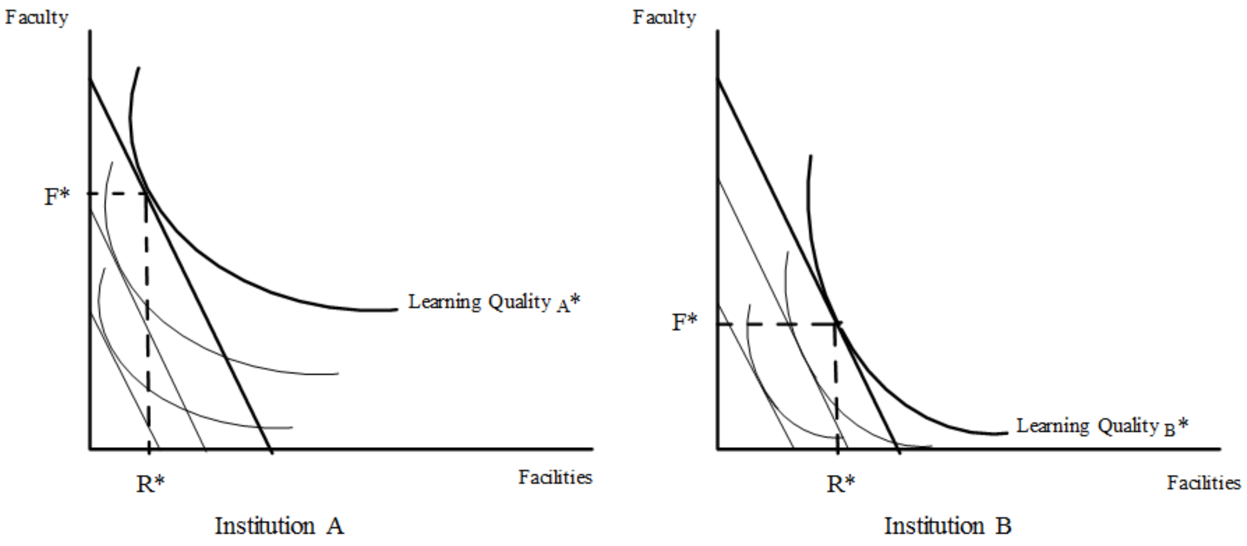
The production function mathematically represents how the institution transforms the inputs (e.g., faculty, students, facilities, etc.) into output(s) (e.g., student learning, research publications, rankings, etc.). (Hopkins 1990) As mentioned above, higher education institutions have multiple products (i.e., outputs), so the function must reflect this. For now, consider just two inputs (faculty and facilities) and one output- student learning. Take the following model:

$$Q = f(\text{faculty, facilities})$$

The isocost curve shows the combination of inputs that cost the institution the same amount. Its slope depends on the relative prices of the inputs. If the institution expands its budget, the curve shifts out (to a point of tangency with a new isoquant, which is on an expansion path from the origin). If the budget is contracted, the isocost curve shifts inward, meeting a new isoquant at a new tangency point. Likewise, if relative prices change between the inputs of faculty and research facilities, the slope of the isocost curve will change and create a new tangency point. Where the isocost and isoquant curves are tangent provides the optimal cost-minimizing point for a given level of production and the point of tangency represents where the ratio of the marginal cost of inputs is equal to the ratio of the marginal products.

The expansion path in Figure 2.2 illustrates the choice of the input mix that minimizes cost given the technology of production. The optimal amount to produce depends on available resources and the amount of other outputs that are produced. In other words, it depends upon where on the multi-product production curve the institution chooses and is able to function. The scenario modeled in Figure 2.2 assumes each institution has the same budget and faces the same relative prices. However, because of the differing objectives the institutions choose different types of outputs to produce and thus a different mix of inputs. The institution focused primarily on student outcomes (Institution A) has an input technology where faculty are highly productive relative to facilities, leading it to hire relatively larger numbers of faculty. The institution focused on lower quality learning outcomes (Institution B) has a technology that emphasizes facilities relative to faculty. Each of these scenarios represents what is the efficient

Figure 2.2: Isoquant and Isocost Curves of Higher Education Institutions



employment of inputs for the institution to achieve their objective at the minimal cost. The following section discusses each major input, its effect on output, and its relation to type of institution.

Faculty

Student outcomes can be measured by different proxies related to teaching: professor quality (measured by evaluations), availability to students (measured in office hours per week) and perhaps even participation in extracurricular programs (such as sponsoring student clubs or activities). Similarly, "quality" research is measured in part by grants obtained, publications (quality and quantity), patents, and presentations made at professional conferences. For this discussion, I consider two different types of faculty inputs: faculty with relatively strong teaching skills and faculty with relatively strong research skills.[17]

In the case of a liberal arts college (or teaching-focused institution), the education of students (i.e., student outcomes) is a higher priority than is research. Therefore, the input of faculty who are strong in teaching skills is chosen over the input of faculty with relative strength in research. More product can be produced for the same cost because the "technology" favors hiring teaching faculty. Because the research requirement is lower than at a large university, the institution may also be able to attract faculty who specialize in teaching. To achieve such output, resources are placed in the areas of

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[17] While there are studies that suggest teaching and research are complements rather than substitutes, for this part of the discussion I will assume each faculty member has a relative advantage of one over the other.

highest priority, so funding flows towards salaries for professors (i.e., away from part-time and adjunct faculty) and away from high-investment research facilities.

In the case of a research university, emphasis is placed on research outcomes, so faculty who produce quality research will be a priority input. Relatively low priority is assigned to indicators of teaching quality, which results in fewer full time faculty teaching undergraduates, low numbers of office hours required, and little participation by the faculty in extracurricular activities (both because of faculty preferences as well as departmental requirements). Resources thus flow towards research funding and away from teaching (i.e., faculty producing quality research are preferred over faculty producing quality teaching). In an effort to minimize cost, this leads to more adjunct and part-time faculty being hired to teach courses. One can think of this delineation of research and teaching between institution type as an example of specialization; it is likely more efficient than the alternative. The question remains, however, which has a greater impact on the production of graduate students?

Certainly, faculty matter in the output of graduate students at the undergraduate level. It is faculty who probably matter most in steering a student towards (or away) from an advanced research degree. This idea will be developed in further sections regarding doctoral student output and its variation between types of undergraduate institutions.

Students

There is a significant difference in the importance of students as an input based on institution type, as the level and quality of student varies by institution and the opportunities for students to spend time together outside of class also vary. The majority of liberal arts colleges have only undergraduates, while research institutions and midtier public universities offer masters and doctoral programs. Liberal arts institutions value strong student outcomes, so they choose production processes that facilitate this. In order to meet the goal of providing quality student experience (and outcomes), many liberal arts colleges carefully choose students who will complement and add to the overall diversity and character of the college and augment the learning environment. Because research is a lower priority objective, reputation is based primarily on output measured through student outcomes and achievements. Many admissions applications for these schools require multiple essays, recommendations, and occasionally interviews.

Research universities, on the other hand, gain most of their reputation and success from research produced, which is much more likely to be a product of graduate students (working with faculty). Therefore, admissions applications to the undergraduate programs are typically brief and ask for only basic information, such as GPA and test scores.[18] Relatedly, control over graduate admissions is usually given to each individual department, while undergraduates obtain admission through a centralized office.[19] More resources are directed toward graduate student programs and funding, as reputation is built through research output.

Facilities

Facilities play an important role in the production of various types of output. For institutions with objectives of quality student experiences, resources are put into state-

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[18] Of course, this is not the case at the very ‘elite’ universities (e.g., Stanford, Harvard, MIT, UVA, etc.), but is typically true of most state universities. Graduate programs are much more selective, and typically these students are chosen by the respective department, while undergraduates are chosen by the “Office of Admissions.”

[19] One reason for this is graduate specialization, whereas majors for incoming undergraduate students are typically unknown or undecided.

of-the-art workout facilities, student centers, dorms, and even college-catered laundry services. At many of these institutions, funding for research labs and equipment is generally not a top priority. At institutions where quality research output is a top objective, funding for facilities goes towards labs and equipment. Certainly, many of these institutions also have state-of-the-art buildings for student enjoyment, but the average square footage per undergraduate student is much higher at traditionally undergraduate (and student experience)-focused institutions (i.e., liberal arts colleges.)[20]

Many facilities and their management are outsourced at larger (and public) universities, leading to less direct involvement by the administration. While outsourcing is certainly a cost issue, it makes sense that an institution is less likely to outsource an operation related directly to a high priority objective (e.g., we wouldn't expect a large research university to outsource management of laboratories – in the same way we expect liberal arts college to internally manage student experience-related facilities).

PhD Output in U.S. Universities

I now turn to a discussion of the production of graduate students, measured as undergraduates who obtain a doctoral degree, particularly in science or engineering. Producing graduate students may be an objective of an institution; it has been shown that schools are judged in part by the career outcomes of their graduates. Graduate school productivity may also be an indirect result of other outcomes: students may be exposed to certain experiences that lead them to consider a graduate degree (e.g.,

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[20] There are exceptions, of course, for example, the workout facilities at GSU are 161,000 sq. ft. (just under 7 sq. ft. per undergraduate student) while the facilities at Anderson University are 132,000 sq. ft. (over 60 sq. ft. per undergraduate student). This also depends on relative costs of building such facilities and the number of on-campus students.

working on a research project, being in classes with students who want to pursue a doctoral degree, etc.). Institutions may also go out of their way to recruit and “buy” students who are likely to go to graduate school in order to raise their reputation directly or indirectly encourage other students to go to graduate school.

How might an institution decide their goal is to output future doctoral students? Applying the model from above (Figure 2.1), assume two products, “PhDs” (i.e., undergraduates who will eventually earn a doctorate) and “Everything Else.” The number of PhDs the school decides to produce will vary depending on the production possibilities frontier and the relative weight the institution puts into graduate education in its objective function. Once the decision has been made, the institution then decides how it will produce these goods.

How can an institution accomplish the objective of producing PhDs? A number of factors have been shown to increase doctoral production: exposure to research experiences as an undergraduate (including working on a project with a professor), peer effects (as mentioned above – graduate-school-attending undergrads may increase the rate at which their peers attend graduate school), good facilities for research (e.g., labs), and off-campus opportunities (in the form of research centers or internships. The optimal input mix is chosen in the same way as illustrated in Figure 2.2 (albeit more complicated because of multiple inputs). The production technology and relative costs reflected in the isocost curves leads to an optimal input mix that produces both PhDs and Everything else. There are many research questions related to these factors. Which of the above has the largest impact? Does the impact of these factors vary by type of institution? These are examples of questions will be explored in later chapters.

Conclusion

This chapter has summarized the approach of higher education institutions regarding objectives, product choice, input selection and how all of these relate to the output of PhD students at the undergraduate level. The next chapter will focus on the individual's decision to obtain a doctoral degree in science and engineering. In Chapter 4 I will estimate a reduced form equation for the output of PhDs, drawing on the theoretical foundations laid out in this and Chapter 3. I will control for factors that can raise output of PhD students, and measure differences across institution type, field, and citizenship status of students.

Chapter III

THE DECISION TO OBTAIN A PHD IN SCIENCE OR ENGINEERING

Introduction

In this chapter, I explore the individual's decision to obtain a doctoral degree in science or engineering. I also explore the timing of the decision, which can fall into three categories: before the individual enters college, while at college, or subsequent to receipt of a bachelor's degree.

The human capital model views graduate school as an investment. Students weigh the future stream of income against the costs of obtaining this income (i.e., the direct and opportunity costs of an advanced degree). A variety of factors affect the decision. For example, the presence of fellowships for study lowers the cost. An economic recession can also lower the cost if the student has few opportunities for current employment. Longer expected time to degree raises the costs, while rising relative salaries for PhDs - due to an increase in demand - can make the investment appear more worthwhile.

Non-monetary factors also affect the decision to obtain a doctoral degree in S&E. It may be that one is motivated by prestige, love of research, or other non-tangible factors. These types of incentives are also discussed here. More realistically, people consider both financial and non-monetary incentives when making decisions about graduate school. Two utility models are presented that combine both types of incentives.

Any study of the decision of whether to get a PhD degree must also address the issue of the timing of the decision. Do people who get a PhD leave high school with a desire for a career in research? Do they decide as an undergraduate? Or do they make the decision after having been in the workforce for a number of years? These questions are analyzed using data from the Survey of Earned Doctorates (SED) and the Freshman/Senior Surveys from UCLA's Higher Education Research Institute (HERI).

The Decision to Get a PhD

Income Maximization

The human capital model has roots going back to Adam Smith (1776), who described acquisition of skills and education as adding to one's talent: "those talents, as they make a part of his fortune, so do they likewise that of the society to which he belongs (227)." Although Arthur Pigou is generally considered to be the first to use the phrase "human capital" in 1928, it was Jacob Mincer and Gary Becker who popularized the idea and terminology in the late 1950s and early 1960s in a series of articles and books. Becker (1964) defined "investments in human capital" as "activities that influence future monetary and psychic income by increasing the resources in people (1)." These activities can take the form of training, education, migration and job information search. While these activities add to human capital, they do so at a cost. Ehrenberg and Smith (2000) classify these costs into three categories: out of pocket expenses (e.g., tuition, moving expenses), foregone earnings, and psychic losses (i.e., education is challenging, job searching can be frustrating, etc.). In sum, the human capital model can provide a framework for explaining how one makes a decision on a certain career path. Rewards to human capital (such as salary, job satisfaction, and working environment) are measured against the costs mentioned above.

Bettinger (2010) adapts Manski's (1993) human capital model to explain how these variables generate a decision for a career or training program (e.g., graduate school) in one field as opposed to another. Specifically, he posits

$$E\left[\sum_{t=K_j}^{T} R^{t-1}\left(y_{jt}\right) - \sum_{t=1}^{K_j} R^{t-1}\left(c_{jt}\right)\right] > E\left[\sum_{t=K_i}^{T} R^{t-1}\left(y_{it}\right) - \sum_{t=1}^{K_i} R^{t-1}\left(c_{it}\right)\right]$$

where R is the discount rate, T represents the working lifetime of an adult, K_i is the length of training required to obtain career *i*, *E[.]* is the expectation operator, and y_i and c_i refer to earnings and the cost of training required to obtain career *i*. The model predicts that the student will choose a given career *j* as long as the net expected earnings (earnings minus cost of training) in this career is higher than that of any other field. Financial aid reduces the "cost of training" while the market for a given career can experience exogenous shocks which lead to either an increase or decrease in the expected income stream, making the present value of one decision greater than the present value of another.

As noted above, several variables can operate to affect the outcome. Some are within the realm of influence of the undergraduate institution; most are not. The first that is not is an increase in graduate level stipends. An increase in the value of graduate stipends for career *j* will decrease the cost of training and therefore increase the number of students choosing to go to graduate school for career *j*. Increases in graduate stipends can be even more powerful than increases in future salary, especially when real interest rates are relatively high and current liquidity and/or borrowing are constrained. In their estimation, Freeman, Chang and Chiang (2005) find that at a relatively high interest rate of 5%, a scientist doing ten years of study (including postdoc appointments) will earn 29 percent of the present value of his income stream during these years.[21]

Freeman et al. (2005) look at the supply response to increases in federal funding for graduate study, in particular the Graduate Research Fellowship (GRF), awarded to citizens or permanent residents by the National Science Foundation (NSF). They examine application volume, award levels and demographic information of applicants from 1952 to 1993. The authors find that an increase in stipend values greatly increases applications, and in turn, the skill of applicants as well as the skill of those awarded.[22] Because institutions awarding stipends often follow NSF's lead of increasing award amounts, the impact is far greater than just the number awarded by NSF.

Present value calculations are sensitive to time preferences and real interest rates. In periods when the real interest rate is relatively high, for example, careers with relatively protracted costs over a number of years will be less attractive than they will during periods of lower real interest rates. For students with high rates of subjective time preference, the present value of a PhD will be low.

Similarly, exogenous changes in the market can cause students to consider alternatives. For example, a decrease in the prospects of career *j* will cause people to shift into career *i*. This can be caused by an over-supply or a change in demand due to

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[21] See footnote 2 in their paper.

[22] NSF uses the term "skill" in their report to reflect strength of applicant pool (e.g., ability, background, accomplishments, etc.).

changes in technology. Freeman et al. (2005) find an increase in applications for GRFs when the unemployment rate is high (although this is secondary to increases due to award level increases, as discussed above).[23] General shifts in the market can have an impact on graduate studies; we are seeing effects of this now due to the economic downturn of the last few years. Graduate applications in most fields are up as job prospects in most fields have fallen.

Some of the financial variables that impact the student's decision are in the realm of the institution's influence. The most important thing that an institution can do to impact the decision to go to graduate school if the decision maker is focused solely on financial rewards is to facilitate the student's ability to receive funding for study. The institution can accomplish this by having established a reputation for sending good students to graduate school and in the process help the student obtain funding for study. Professors and departments also write reference letters for students to help them gain admission and funding to top programs. The reputation of the institution can also affect the quality of the graduate program the student is admitted to and, by extension, future earning prospects of the student.

Clearly, money is a motivator for many students, but not the only one. The next section discusses varying non-monetary reasons one might choose to obtain a doctoral degree in S&E.

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[23] The national unemployment rate in this case was related to application increases, however it can be the case that specific field unemployment rates drive graduate school applications (i.e., overall unemployment rates and field unemployment rates do not necessarily move in tandem).

Non-Monetary Motivated Decisions

Most individuals choosing careers in science and engineering are not motivated exclusively or primarily by money. As Freeman (2005) explains, monetary incentives do play a role, but mainly for those on the margins. While some may be set on a career in science because of their love of the field and others motivated simply by money, those on the margins can be lured into becoming a PhD when the market is right, or discouraged when the market is not ideal.

By way of example, consider Table 3.1, which shows present value for varying graduate school paths in the biological sciences (Stephan 2012) compared to getting an MBA degree.

Table 3.1: Projected Present Value ($US), Lifetime Earnings of an MBA & of a PhD

MBA Degree	PhD (7 years to completion)	PhD (8 years to completion)	PhD (7 years to completion & 3 year postdoc)	PhD (7 years, support in graduate school)
$3,230,642	$2,011,385	$1,902,261	$1,957,962	$2,176,938

Note: taking a position in a research university in a biological or biomedical field

At a minimum, the MBA is worth at least $1million more—making it clear that money is not the only factor in the decision making process. Thus, it is important to consider other than monetary rewards to science.

What might these rewards be? Some researchers are drawn by the nature of the work. Others are drawn by the potential for prestige or recognition. To draw on the work of Stephan and Levin (1992), the rewards to science and engineering include the puzzle, the ribbon and the gold. The puzzle represents the pleasure derived from finding things out, while the ribbon represents prestige, and the gold represents money.

Still others find that the prospect of helping society can play a strong role in motivating scientists, at least once they are established in their careers. Sauermann et al. (2010) use survey data from over 2,000 scientists and engineers to study motivation for patenting. They find that while financial incentives appear to play an important role in the physical sciences, in the life sciences the motivation of contributing to society is the most important factor. For engineering, advancing in one’s career as well as mastering a challenge are key motivations for patenting. A number of other papers have researched these issues and have tried to identify the impact of non-monetary factors in the decision process. Arcidiacono (2004), for example, looks at personal benefits from preferences for a given major, and finds sorting into majors (controlled for ability) is due to variations in preferences as opposed to financial returns to a major.

Roach and Sauermann (2010) surveyed a sample of graduate students and postdocs in the United States, in which they collected over 6,000 responses from advanced PhD students and postdocs in the life sciences, physical sciences, engineering and computer science. The survey posed the question, “Thinking back to when you began your PhD program in [year], how important were the following factors in your decision to pursue a PhD?” and had many responses indicating preferences for non-monetary rewards in addition to a preference for higher salaries. Each factor was ranked from one to five, five being the most important. Having been always interested in research, completion of a requirement for desired career and curiosity about one’s field are the top motivators, all scoring between 3.75 and 4.5 for all fields. Somewhat lower is the status a PhD provides, with an average score of around 3.5 for all fields. Last (and considerably lower than other factors with an average under two) is a difficulty in finding another job.[24]

Again, the question arises as to what an institution can do to attract and encourage students motivated mainly by the reasons mentioned above to get a PhD. In this case, the news for institutions is better – they can have a bigger impact on non-monetary factors much more so than the financial returns a student will receive once out of college. For example, puzzle-solving can be cultivated through a research-focused curriculum and creative teaching. Students can experience the satisfaction derived from recognition by participating in research projects on which they are a co-author. They can also become socialized to the importance of recognition by observing the importance faculty and the institution ascribe to the prestige that accompanies publishing in top journals. For appealing to the desire of students to help society, institutions can partner with hospitals and labs known for a commitment to serving the community.

While each of the above approaches to decision-making is feasible, it is more probable that a student uses both factors (financial and other incentives) when deciding to go to graduate school. The next section presents a model that combines both types of incentives into a utility maximization problem.

Utility Model Approach

As noted above, some may decide to enter a career in S&E based strictly on pecuniary rewards; some strictly on non-pecuniary rewards (such as a love for science

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[24] Foreign students were asked about motivation from a desire to obtain a US Visa; this averages between 1.9 and 2.5 for all fields, with chemistry and engineering being motivated the most.

or pursuit of prestige). However, a more realistic approach is a decision based on some combination of monetary and nonmonetary factors. Levin and Stephan (1991) model a decision process related to productivity which includes both types of rewards.[25] Individuals allocate time across research and non-research activity (e.g., teaching), and maximize utility based on research output and market goods (purchased with income made from research and non-research activity). This model is discussed in more detail below.

Other models rely on identity to explain behavior. For example, adapting a model used by Humlum et al. (2010), taken from Akerlof and Kranton (2000), the utility model presented below integrates "identity" (used often in sociology and psychology) with pecuniary returns to a given career path. "The idea is that social identity can explain behavioral variation within a population with identical expected economic payoffs (4)." In social identity theory, each person belongs to (and self-identifies with) a given social category. Deviations from this category produce disutility.

The adapted utility model is presented here:

$$U_i = U_i(a_i, I_i) \tag{1}$$

where a_i represents the actions of individual i and I_i represents the self-image of individual i. $I_i$can be expressed as the following:

$$I_i = I_j(a_i; a_{-i}; c_i; \varepsilon_i; \beta) \tag{2}$$

So, self-image is a function of one's own actions, the actions of others, his social category (c), exogenous characteristics (ε), and the accepted/ideal behavior for his social category (β).

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[25] Levin and Stephan (1991) model productivity, not career choice, but their model can be applied to career choice.

Assume career choice is a result of effort towards a degree (e), and that an individual chooses this career to maximize utility. Using (1) from above, we can write the revised utility function as follows:

$$U_i = U_i(w(e_i; \varepsilon_i); I_i(e_i; c_i; \varepsilon_i; \beta) \tag{3}$$

where $w(e_i; \varepsilon_i)$ is the income of individual i given his career choice e_i and exogenous characteristics ε_i. Income and identity depend on both the characteristics and the behavior of i. So, for example, if one belongs to a category (i.e., social class) that dictates certain degree and/or field of employment resulting in relatively lower pay (e.g., PhD in history vs. JD; college professor vs. corporate lawyer), one could rationally choose to pursue the former. If utility were based solely on income, no one with the ability to become a corporate lawyer would choose to pursue a PhD.

While this model incorporates the idea of monetary and non-monetary rewards contributing to utility, it does not include utility coming from a love of performing research. Levin and Stephan (1991) posit a greater taste for research leads to a greater proportion of one's time spent in research, as the reward of "puzzle-solving" brings utility -- not just because puzzle solving increases the incentive to produce research output that is rewarded in the market, but also because the individual derives satisfaction from the process of producing research. The authors present a model with a similar approach as above in combining both financial incentives and non-monetary incentives (which they refer to as investment and consumption motives). Consumption motives reflect the desire of a researcher to do research because of the personal satisfaction involved (whereas the model above reflects the desire for respect and prestige). In this model, utility is a function of market goods, (i.e., income) and research output. One chooses the proportion of time she spends engaged in the production of research in order to maximize her utility.

In addition to why one gets a PhD, another important question is when the decision is made. The next section outlines three possible decision points and discusses how to deal with these empirically.

When is the Decision Made?

In order to simplify the timeline of decision making, consider three points in time where one might decide to obtain a PhD: (1) before entering college, (2) during college (undergrad), or (3) significantly later. An undergraduate institution may admit, teach, and graduate a student who has always (i.e., pre-college) planned on obtaining a doctoral degree. Or, the undergraduate institution may admit a student with no plans for an advanced degree, but by the time he graduates, he plans to obtain a PhD. The third scenario is a student who graduates from an undergraduate institution with no plans for an advanced degree, but later makes a decision to return to school. She may be encouraged (and even funded) by her firm, or she may have discovered an interest in research later in her career. Because my research question is related to the role undergraduate institutions play in PhD output, this chapter will focus on the first two decision points.

Deciding Pre-College

Consider the first decision point: before entering college. The issue here is selection. If a student decides while in high school – or even before - to get a PhD, he will seek out colleges that put him in the best position to obtain a PhD. He will select institutions with a proven track record of placements into good programs, earned fellowships for graduate study, and the possibility of having a research experience as an undergraduate. The reputation of the faculty may also play an important role. Some students wishing to follow a career in science and engineering may be attracted to attending an institution that boasts prestigious faculty, research facilities, or high publishing rates. A strong emphasis on research may, on the other hand, discourage students with an interest in science from attending the undergraduate institution if they fear that the emphasis may make it unlikely that they will actually have contact with research faculty and instead be instructed largely by graduate students.

Student pre-enrollment plans may also affect the institution's selection process. Many applications require students to indicate career goals and potential majors, giving the school information that cannot be observed simply from transcripts or standardized test scores. Consider an institution that wishes to increase its PhD output. Such schools will seek out – and possibly reward – students indicating a desire for a PhD. Institutions can offer scholarships, research assistantships, or admission to special programs (e.g., honors colleges) to lure students who show an interest in getting a PhD in order to increase their rate of producing PhDs.

When modeling productivity, I will need to control for both types of selection. I can use HERI data to measure the level of incoming freshman who plan to obtain an advanced degree and compare it to the actual rates of graduate school attendance. While I do not know the particular school (HERI withholds school identifiers), I do know the school type (both structure and selectivity) as well as student demographics. I plan to construct a variable for each type of institution (22 different stratifications from HERI). This variable will measure the difference between planned graduate school and actual graduate school attainment by type of institution. I can also include school-type level variables related to demographics and planned majors. The inclusion of such a variable will help control for selectivity. The “cost” of including such a variable will be the strong colinearity between the variable and the type of institution.

There are additional considerations. Not all students who, at 17 or 18, want to earn a PhD will continue to have the same career goals upon college graduation. In other words, retention of these students is crucial. There are two types of retention issues to consider: first, the student must be retained at the institution through graduation. Second, and what will be discussed in greater detail later in this chapter, is the retention of students within the S&E majors.

An institution, of course, may be excellent at attracting students and selecting students who know prior to entering college that they will want to get a PhD. But retaining these students is crucial to allow them the chance to continue to graduate school. Some institutions are able to retain students in their chosen major; other institutions are less successful at doing so.

Institutions can impact retention in various ways. Some institutions have a culture of ‘weeding out’ students in the sciences early on. While the approach may be successful in filtering out students who are not serious about and/or capable of a degree in the natural sciences, these types of departments may discourage potential PhDs right out of the major (or even the institution). There are positive approaches to retention as well. Institutions—as noted above-- can provide meaningful research experiences, exposure to prominent faculty members, and academic advisors within the department in order to encourage students to stay in the major. They can also provide summer research experiences.

In addition to retention within S&E, programs can recruit students from other majors. Many institutions, however, have a difficult time recruiting students into the sciences; the outflow greatly exceeds the inflow. The following section presents results from studies of major switching, recruitment and retention in the sciences.

Empirical Results: Retention and Recruitment in S&E

Applying the Manski model presented above, Bettinger (2010) explores the individual's choice of major. The idea he presents is that a student will choose a major if the expected present value of lifetime utility for their given choice of major is higher than the expected value of any other major (earnings minus cost of training). One fact supporting this theory is that American students have shifted away from S&E majors towards more vocational training-type courses and majors (such as business or nursing). Results from a HERI study show that there is an increase in the percentage of American college freshmen who value being “very well off financially” in the future and a corresponding decline in the percentage who list as a priority to “develop a meaningful philosophy of life” (Pryor et al. 2007).

According to the National Center for Education Statistics (2009),[26] full-time enrollments in undergraduate degree programs increased 46% between 1979 and 2002, while enrollments in S&E majors increased by only 31% during that time (Bettinger 2010). However, this number is misleading, because computer science

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[26] Higher Education General Information Survey: "Fall Enrollment in Colleges and Universities."

majors increased by almost 500% during this time, while math and physical sciences showed a decrease in enrollment (and degrees) over this period (i.e., much of the growth in S&E can be attributed to computer science). In addition, the growth in S&E is due to women entering these fields. Women's degrees grew by 91% between 1977-2000; degrees awarded to men in S&E, however, decreased during the same period.

Ryoo and Rosen (2004) model the decision of an undergraduate to choose engineering as a career (and major). The authors estimated supply and demand parameters from 1950-1990, and found that changes in demand for (and subsequent employment of) engineers are significantly correlated with changes in national defense and R&D expenditures. A lag exists – when R&D and defense spending is low, undergrads move away from engineering. This can cause a shortage by the time one cohort enters the labor force (e.g., the low spending in the 1980s resulted in too few engineers in the 1990s). Ryoo and Rosen also find that future engineers respond quickly to economic conditions. The relative supply of engineers (as a share of college graduates) is highly correlated with the real present value of an engineering degree, which suggests relative earnings are a motivating factor in the decision to pursue engineering.

Bettinger (2010) also finds major choice to be correlated with perceived future income. He works with a dataset from the Ohio Board of Regents, which includes transcript-level data for all public universities in the state of Ohio. He finds (for Ohio public schools) that almost half of students who switch out of S&E majors switch in to business, which he attributes to increases in business wages. Overall, S&E majors retain only 50-54% of original S&E declared majors.[27] As for those switching into S&E fields, only 7-9% of non-S&E majors make the switch. He also finds that women switch out of S&E majors at a much higher rate than do men. In contrast to this result, a 2011 report from the National Academies of Sciences finds that women actually persist in S&E majors at a slightly higher rate than men (although they have a much lower rate of choosing an S&E major).[28]

Relatedly, another factor in major selection, according to Freeman and Hirsch (2008) is job content, not only predicted wages, and this factor's impact varies between men and women. They find women respond strongly to changes in the content of jobs (e.g., an office assistant at one time primarily typed memos and answered phone calls; now that same assistant has a much wider and varied range of job tasks). Men respond more strongly to changes in wages as compared to women, and much less to changes in perceived job tasks.

There are differences across race as well when looking at S&E majors. Minorities persist at a lower rate than whites, and the NAS report suggests this is due to a lack of support from the institution for minorities, being the first in the family to attend college, and being from a low-income family. Richard Sander (2004) suggests one reason for low completion rates could be what he calls the "mismatch hypothesis," the notion that minority students are not successful in science when they attend an institution with standards far exceeding their background. However, a number of studies have found

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[27] Perhaps related to this decision is the finding that business majors do less to prepare for class than students of any other major (see Glenn 2011).

[28] These differences are likely due to a difference in samples. Bettinger uses Ohio Regents data on all public Ohio Universities, while the NAS report use NSF datasets (e.g., National Science Foundation, Women, Minorities, and Persons with Disabilities in Science and Engineering), which are more likely to be representative of the undergraduate population as a whole.

the opposite. Bowen and Bok (1998) use College and Beyond data and find that for minority students,[29] attending a highly selective institution is correlated with higher probabilities of attending graduate school, participating in leadership in one's community and greater career success (measured by income). While Espenshade and Radford (2009) report that minorities are less likely to graduate and more likely to have a lower GPA than white and Asian students, they conclude that Bowen and Bok's results hold: going to a more selective institution provides greater opportunities throughout life, regardless of the lower standing in class rank. Alon and Tienda (2005) find that as selectivity of the institution rises, the probability of graduation for minority students increases.

What might be a factor in a student's decision to stay in an S&E major? According to Bettinger (2010), students declaring an S&E major who take more S&E hours in their first semester of college are much more likely to remain in their major than are those who take few S&E course hours (63% vs. 42%, respectively). He admits this could be because of selection: "students who take fewer STEM [S&E] courses may be identifying themselves as students who want to defect…[students] taking more courses may generate more interest and consequently, more commitment to the STEM major (87)." For minority students, financial aid is very important: the National Research Council (2005) finds merit-based aid is positively correlated with completion rates. "[W]hen such support is lacking, undergraduates who are already greatly challenged by a demanding research program, in addition to a full course load, take on additional

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[29] All majors included, the study is not restricted to S&E.

outside work to make ends meet, which is a ‘recipe for disaster’ as one program administrator put it (8).”

Why might a student switch majors? Paul Romer (2000) discusses a report by the College Board, where the grade distribution in second-level courses (for example, Calculus II or English Literature II) was examined. When a student earns a certain grade on an AP exam, they typically “place” into a more difficult course. For example, a student earning a 2 of 5 on the Calculus AP exam would not earn placement and therefore would take Calculus I to fulfill his math requirement. However, the student earning a 3 of 5 would place out of Calculus I and into Calculus II. These “II” courses tend to be biased towards students majoring in a related field (because most non-field students take the “I” level for the requirement and move on to their major coursework or other field requirements). The College Board compared the grades in the “II” level courses that were taken by students placing into the class. The results clearly show the distribution of grades in history and English were much higher than in mathematics (80%, 85% and 54% of students received an A or B, respectively), which supports his theory of making S&E majors less attractive by ‘weeding out’ students relatively early on.

Does the type of institution matter? Romer (2000) claims it does. He looked at why liberal arts colleges grow science and engineering graduates at a lower rate than other types of schools. His theory is that liberal arts colleges have little incentive and pressure to increase the size of their departments based on changing market demands. Because these schools have fixed department sizes which face internal pressure to remain relative in size to other departments in the institution, it is difficult for certain departments to grow, even when the demand increases. The resulting effect, then, is for the department to make the program more competitive - weeding students out of the major - so as not to have too large an increase in major size (resulting in greater teaching loads). Other departments will try to attract students by relatively easier coursework.

When considering PhD output, the story presented by Romer is counterintuitive at first glance: how is it that liberal arts college lead in S&E productivity of doctorates, but also do not grow S&E departments as fast as larger institutions – resulting in lower numbers of S&E majors than other types of institutions? The obvious answer is that S&E majors at liberal arts colleges have a substantially higher propensity to obtain a PhD than those at other institutions. This actually can indicate an underestimation of the PhD output of liberal arts institutions. In other words, while these institutions may be relatively poor in retaining S&E majors, students at liberal arts institutions who actually do complete their degree get a PhD at a much higher rate.

Deciding While in College

The second decision point regarding whether to get a PhD occurs after the student is enrolled in undergraduate study. The majority of these students have come with an interest in majoring in science and engineering, but have not originally planned to go on for a PhD. A few are recruited into majors in science and engineering during their years in college.

As discussed in Chapter 2, there are a number of things that an institution can do to encourage such students to choose to go on for a PhD. Generating graduate students may come from exposure of students to experiences that lead them to consider a graduate degree (e.g., being in classes with students who want to pursue a doctoral degree, working on a research project, etc.). Therefore, institutions can implement requirements such as a senior thesis to encourage students to go to graduate school through exposure to research. Peer effects can also play a role in graduate school attainment; institutions may recruit and "buy" students (through scholarships) who are likely to go to graduate school. These students may raise the institution's reputation and can impact other students' decision to go to graduate school.

For this second decision point, I can use the same HERI data to measure the percentage of exiting (i.e., graduating) seniors with a desire for obtaining an advanced degree. Students in the first case mentioned above will be treated as if the institution had no effect on their choice.[30] It is the second type of student I want to quantify and compare across institutions. Because these percentages are not the actual students attending, but those with plans or goals to attend, I will compare the change in percentages across institutions, conditional on student expectations. Table 3.2 presents

Table 3.2: HERI Freshman/Senior Survey Summary of Graduate School Plans

	Observations		% Planning Grad School*			% Attending Grad School
School Type	Schools	N	1992	1996	Δ	1996
Public University	2	294	75	85	10	15
Private University	8	1019	81	79	-2	29
Public 4-yr College	5	869	78	80	2	13
Private Secular 4-yr College	20	2346	80	75	-5	23
Catholic 4-yr College	19	1812	73	74	2	26
Other Religious 4-yr College	27	1482	64	76	12	23
HBCU: Other Religious 4-yr	3	131	79	60	-18	44

Source: HERI Freshman (1992) and Senior Survey (1996), UCLA

*This applies to any type of advanced degree program – PhD, MA, JD, MD, etc. The survey question does not specify the type of degree.

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[30] While the institution may have been selected by the student for its ability to prepare them for a graduate education, I assume there are no influencing factors while in school (i.e., the student wasn't convinced to go to graduate school by any professor, class, program, etc., as she already had her mind made up while applying to college).

summary statistics on these two issues. The most important variable for my analysis is the change in those planning on graduate school. For each institution type (which can be further delineated by degree of selectivity in admissions), I will assign this change variable as a proxy for encouraging or discouraging graduate school while at the undergraduate level. In addition, the percentage attending graduate school will also be valuable in measuring actual results of the institutions by type. Again, the “cost” of including such a variable will be the strong collinearity between the variable and the type of institution.

Deciding Post-College

Given the focus of this dissertation, I wish to exclude from the analysis individuals who make the decision to get a PhD subsequent to receipt of a BA degree. This is easier said than done. While looking solely at the time between undergraduate and graduate school could be one approach, it may be the case that a student realizes her desire for a doctoral degree while an undergrad, but does not act on that desire until she has been working for some time. The HERI data provide information on those desiring to attend graduate school as well as those actually enrolled for the fall. The residual value between the two can be a proxy for how many students desire an advanced degree coming out of undergraduate school but do not act on the desire.

However, it is much more likely for one to decide to get a PhD well into his career.[31] The best way to measure and account for these cases is to look at elapsed time between undergraduate exit and doctoral program entry. This time averages 1.14

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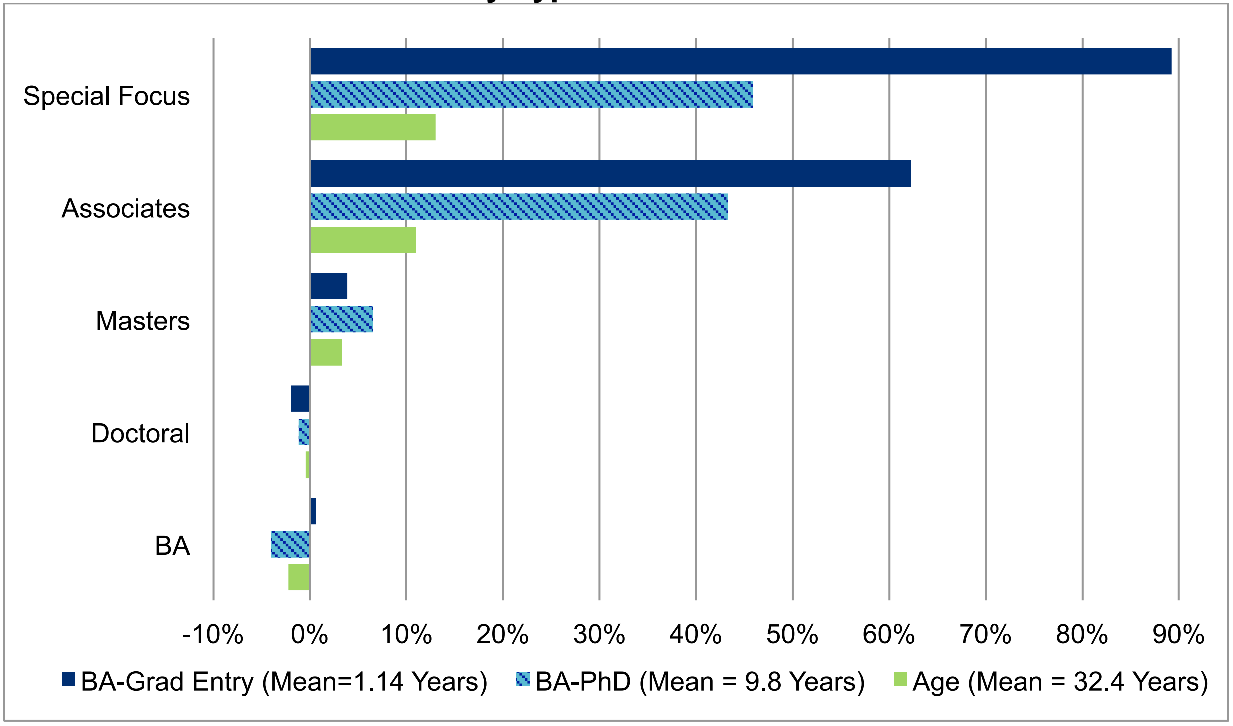
[31] Of course, there will be no way to differentiate this, but a measure for a desire to attend graduate school at college exit (from the HERI dataset) could be used as a proxy.

years but varies across fields and individuals and is associated with the type of undergraduate institution. Likewise, there is variation in the mean age for receipt of degree (average 32.4 years) and time between completing a BA and a PhD, which averages 9.8 years. The following figure presents the percentage difference from the mean by type of institution for each of these three averages. A 10% difference from the mean of age translates to 3.2 years (e.g., the average age of someone from an Associates institution is 11% higher than the mean, or 36 years).

Figure 3.1: Percent Different from the Mean, Time to Degree and Age by Type of Institution

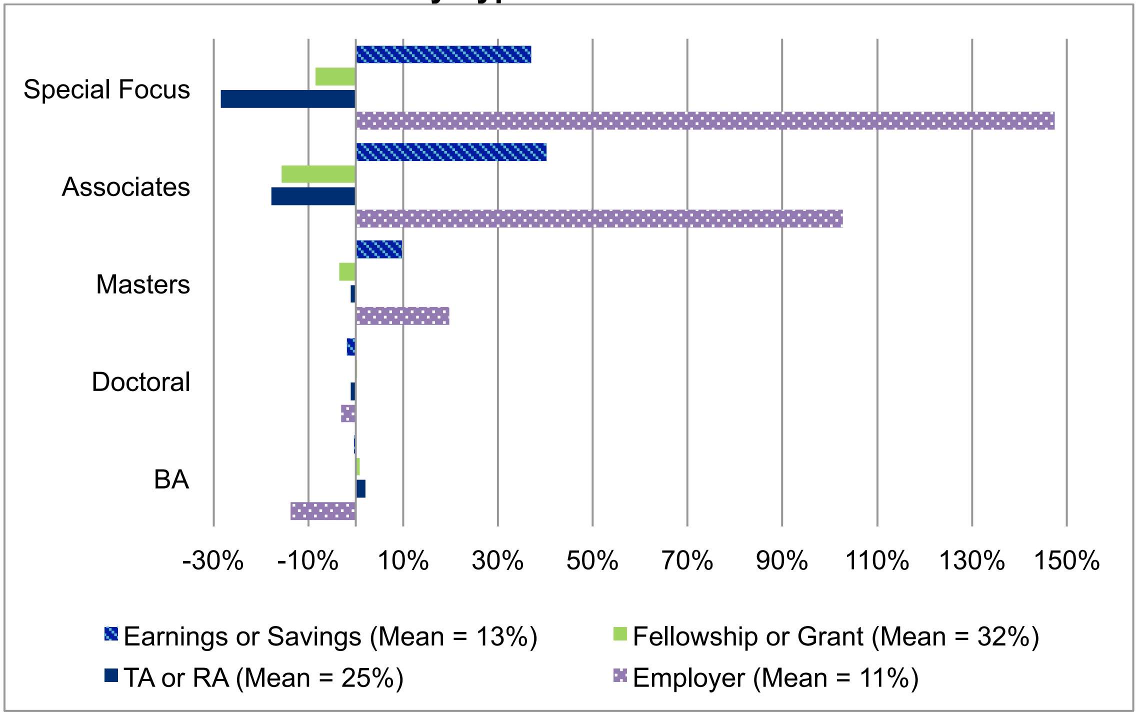


Source: SED. 1981 – 2008. Fields include all Science (Life, Health, Physical, CS & Math, and Economics). Special Focus institutions include profession-specific schools, such as seminaries, nursing schools, etc.

As can be seen, there is a significant difference between types of institutions. Those from a BA undergraduate school are the most likely to be younger and have the least amount of time between graduating from undergrad and receiving a PhD.[32] Those coming out of special focus and associates institutions are much more likely to be older, and take more time between BA and graduate school as well as between BA and PhD.

Another factor lending insight with this timing of the decision to get a PhD is the source of funding. Many of these cases are people employed in industry, encouraged by their supervisors to return to school and often paid or supported by their employers for graduate study. The following figure shows, by type of institution, the funding sources of those with an S&E PhD.[33]

Figure 3.2: Percent Different from the Mean, Funding Source by Type of Institution



Source: SED. 1981 – 2008. Fields include all Science (Life, Health, Physical, CS & Math, and Economics). Special Focus institutions include profession-specific schools, such as seminaries, nursing schools, etc.

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[32] The average time from graduate entry to PhD is 8 years. By type of BA institution: LA graduates average 7.6 years, Masters institution graduates average 8.6 years, and doctoral institution graduates average 7.9 years. I also have this information by field, but for now it's too cumbersome. I should be able to update this once I choose exact definitions of sub-fields.

[33] Question phrasing: "This question is about your sources of support during graduate school. Did you receive support from the following sources?"

Illustrated above, those coming out of special focus, primarily associates, and masters institutions are much more likely to be funded by their employer or through savings/earnings than those from doctoral or BA institutions. This correlates with their age at time of degree, as these schools are more likely to produce PhDs who begin graduate school later in life. On the other hand, those from BA institutions are more likely to have been funded by a research or teaching assistantship, or fellowship.

Conclusion

This chapter has summarized the individual decision process regarding graduate school. This decision involves considerations of costs, monetary rewards, and non-monetary rewards such as interest in a certain field. The timing of this decision varies from pre-college to many years after college. Institutions can increase their PhD output through knowledge of the decision process, such as recruiting students with a desire for doctoral degrees or by providing certain experiences for undergraduates. The next chapter will focus on the intersection of these two ideas. I will estimate PhD output at the undergraduate institution using aggregated individual data. Differences across field and institution type will be further explored.

Chapter IV

DETERMINANTS OF S&E PHD OUTPUT AT THE UNDERGRADUATE LEVEL

Introduction and Research Question

In previous chapters, I have discussed theories underlying the output of doctoral students at the undergraduate level, as well as the individual's decision to obtain a doctoral degree in science and engineering. This chapter explores empirical evidence based on several datasets using a reduced form model to estimate the impact of institutions, individual preferences and research exposure on the output of doctoral students in science and engineering. Questions addressed include: (1) How does output of PhD students from liberal arts schools differ from that of research universities, and, within the liberal arts institutions, how does it vary by type (ability, demographics, etc.) of student and school? (2) How does student selection affect the analysis of schools - that is, are certain schools particularly good at attracting students committed to graduate school, while other institutions are particularly adept at "producing" graduate students?

Answers to these questions have some important policy implications. At the micro level, what can institutions do to increase (or decrease) output of S&E PhDs? At the macro level, are there policies the government can implement that will increase the output of PhDs and, indirectly, the level of innovation in the United States? The timing of these policies is also important. For example, if it is the case that individuals are not influenced by undergraduate experiences but instead come to college committed to a course of study, it may be useful to increase funding in primary and secondary schools to encourage an early interest in science and mathematics. But if institutions matter and students' decisions are formed in college, policies should be geared toward the undergraduate experience. To the extent that graduate stipends matter, policies should be aimed at augmenting support for graduate study. The following model and results will guide answers to these questions.

The outline of this chapter discusses first the model and descriptions of the datasets used. Next, I estimate the model and present extensive results for overall S&E PhD output. Finally, I present results for PhD output by field.

The Model

Chapters II and III looked at the two decision-making entities related to the research questions: institutions and students. Consider the institution: how can it accomplish the objective of producing more PhDs?[34] From other research, we know that certain factors lead to increased production,[35] such as exposure to research as an undergraduate, peer effects, good facilities for research, and off-campus opportunities. Which of the above has the largest impact? Does the impact of these factors vary by type of institution? From the point of view of the student, what factors might increase her chance of attending graduate school? Some are swayed by the stipends offered to PhD

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[34] While S&E PhDs are not the only sector of PhDs, they are the ones most likely to directly impact innovation that can lead to increases in economic growth. Additionally, S&E PhD programs are significantly different from most non-S&E (time to degree, type of student they attract, and admission requirements). Therefore, "production" discussed in this chapter refers solely to S&E PhD output.

[35] See Chapter II.

students, some make their decisions based on the state of the economy and still others by non-monetary factors, such as their love of science.[36]

The goal of this chapter is to examine such questions by estimating a reduced form model that includes both institution variables (ITV_t) and student supply variables (SV_t).[37] The dependent variable, $P_{t,}$ is the yearly PhD output rate of an institution expressed per 1000 students, defined as

$$P_t = \frac{\text{number of students who graduate from an institution and earn an S\&E PhD from by 2008}}{\text{total undergraduate enrollment of the institution in year t}} \text{ x } 1000$$

and hypothesized to be a function of ITV_t and SV_t.

Other studies, most notably the Burreli et al. NSF report, use as the denominator some measure based on graduates instead of enrollment. I choose to use enrolled undergraduates as the denominator variable because part of producing students to attend doctoral programs includes producing students who graduate from an undergraduate program. Using graduates only would not control for differences among institutions in moving students from undergraduate admission status to graduation. As some of my key variables test the influence of faculty encouragement and support on subsequent outcomes, I want to allow for this institutional effect. Therefore, I prefer the use of enrollment rather than graduates in my denominator.

A disadvantage of using enrollment as the base, however, is that if institutions have widely varying graduation rates due to their initial mix of students and not due to their educational effectiveness, part of what appears to be high “productivity” reflects selection instead. Thus, examining the sensitivity of our results to a different formulation of the dependent variable will be helpful in understanding the extent to which selection

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[36] See Chapter III

[37] These are described in detail below.

may affect the results. In Appendix A, I present results and discussion from two main regressions using graduates as the denominator.

Because the dependent variable is bounded between 0 and 1000, I use a Tobit regression model to account for the sometimes binding lower bound. First, I look at the relationship of PhD output of the institution to tier and time, and then add in variables that measure the economic climate. Next, I add institution variables and student variables, excluding the variables for tier. I then estimate equations separately by tier and by field. Finally, I use data from the HERI survey to try to get a better fix, be it for only one year, on the role that selection plays in PhD output. The following section describes the data in detail and the variables employed in the analysis.[38]

Datasets and Variables of Interest

Survey of Earned Doctorates

The Survey of Earned Doctorates (SED) is administered by the National Science Foundation. The annual SED, begun in 1957, surveys every graduate of any U.S. university with a research doctoral degree. According to NSF, a research degree is “a doctoral degree that (a) requires the completion of an original intellectual contribution in the form of a dissertation or an equivalent project of work, and (b) is not primarily intended as a degree for the practice of a profession.” Therefore, medical doctors, doctors of jurisprudence, etc. are not included in the survey. Individual schools administer the survey to their students at or near the time of graduation. Although numbers have fluctuated over the years, the most current survey results (2009) show over 49,500 doctoral recipients from 416 institutions.

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[38] See the “Estimations” section below for an extensive discussion of the model.

While SED response rates have fluctuated over the years, they are always above 90 percent and many times above 95 percent. I have access to the 1980-2008 survey data. Variables included are demographic information (age, gender, race, citizenship status, etc.), time to degree information (including time off between degrees), undergraduate school and field, PhD field, and future plans and funding sources, among others.

Thomson Scientific Web of Knowledge

As a proxy for a student's exposure to research as an undergraduate, I use counts of publications by field and quality of publication[39] at each PhD graduate's undergraduate school. In order to do this I use a dataset from Thomson Scientific Web of Knowledge, compiled by Wolfgang Glänzel, Department of MSI, Centre for R&D Monitoring, K.U., Leuven, Belgium. The data consist of all journal publications from all fields and all types of institutions (universities, research centers, government, etc.). I have narrowed the set to U.S. colleges and universities. Years 1991 – 2007 are available, with publications per school listed by year, field, and number of authors.

The College Board

I have received eight years of data from the College Board. These datasets include over 1300 variables for each higher education institution in the United States. I have obtained the odd years from 1987 to 2001, and have interpolated key variables for even years.[40] The variables included in these data that are of most interest to my work

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[39] As defined by a list of "top" journals within the Web of Knowledge dataset.

[40] Each year was sold individually directly from the College Board. In order to hold down costs, only odd years were purchased.

are student and faculty demographics, counts of foreign students and funding, detailed admissions and enrollment information (including test scores), and the percent of students obtaining advanced degrees.

Higher Education Research Institute

Finally, I have been granted access to the Freshman Survey and the Senior Survey, administered by the Higher Education Research Institute at UCLA. These surveys are administered at a number of institutions around the country. The Annual Freshman Survey (for which I have data for 1992) has a much longer history (it dates back to 1965) and therefore is much more widely administered than the Senior Survey. The College Senior Survey (for which I have results from 1996) began in 1993. Universities may purchase reports and compiled data from HERI.

The HERI dataset is rich with a variety of valuable measures, although it covers only 84 institutions. For example, from the freshman survey, I have data on probable major, funding sources for college, reason for attending a certain college, citizenship status, race, whether the student is likely to change majors, test scores/HS GPA, parents' income and education, and highest degree planned to obtain. From the college senior survey, I know completed major, if the student changed majors, if the student worked on a research project, the types of interactions students had with professors, and plans for graduate school.

With the HERI data, student responses can be linked, so a student can be tracked from freshman to senior years.[41] I aggregate these data at the institution level,

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[41] HERI does not release school-level identifiers, and compiles the dataset based on survey-takers of both surveys. Therefore, there is some level of selection inherent in the data, as only those graduating in

creating a proxy for variables of interest (e.g., exposure to research, plans for graduate school, etc.). While institution level data are not released, there is an institution ID variable and also the type of school ("Top Research", Tier 2, etc.) indicator. I use the ID to link to institution data and can then measure variation in student characteristics and experiences across 21 of the HERI school types. These variables will be used to correct for selection (i.e., to what extent certain schools attract already-motivated future doctoral students).

Variables of Interest

The dependent variable is a rate and is measured at the institution-year level, where year is the undergraduate graduation year and institution is the undergraduate institution. In other words, for each institution and for each year (1990 to 2002), the rate is defined as the number per 1000 enrolled students who earned a PhD by 2008 in S&E.[42] The lower bound on time of BA degree is 1990. This date is chosen because the first year the publication data are available is 1991, and I assume that the research for a publication appearing in 1991 was conducted two years earlier. Furthermore, I assume the most likely year of exposure to research that is published is the student's junior (i.e., third) year. Thus, research done when the student was a junior would be published one year after graduation.

The upper bound of the time period is chosen to be 2002. Given that the SED data are available through 2008, this means that for the BA year of 2002, the rate is the number of 2002 graduates completing a doctoral degree within six years of graduating

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four years are included in the survey. Students who enter, but do not graduate, college and students who take longer than five years to complete undergrad are omitted from the survey.

[42] S&E includes life sciences, physical sciences, mathematics, computer science, engineering and economics.

undergrad per 1000 enrollees at an institution. Moreover, and as a result of the truncated nature of the PhD data, the rate for the last few years declines steadily, reflecting the fact that average number of years between a BA degree and a PhD is nine – although many complete the PhD in five or six years upon graduating with a BA. Results from the most recent period may provide information on the types of schools that send students straight on to a PhD program as well as the types of institutions that prepare students to complete their studies in a timely manner. To correct for the truncation issue, I control for time trends in all estimations.

A number of factors are hypothesized to affect the rate of PhD output of an undergraduate institution. To begin with, institutional factors matter, as discussed in chapter 2. Peer effects matter: a higher-ability and more traditional student body should produce a higher rate of doctoral students. Peer effects are enhanced the more students interact. Therefore, more traditional college settings as reflected in the age of the student body and the percent living on campus may enhance peer effects. I measure traditional student populations by average age of freshman and campus residency by percentage of students living in college housing.

Other institutional characteristics are hypothesized to matter as well. These include faculty research, measured here as the number of top publications per faculty[43], and the percentage of overall faculty with advanced degrees. The latter is hypothesized to be positively related to PhD output not only because the measure reflects research skills but also because faculty with PhDs have more knowledge of the process of obtaining a doctoral degree, and therefore can better assist students in the application

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[43] Top publications are defined within the Web of Knowledge dataset to include publications in journals classified as most selective – or top tier - within each field.

process. Top publications are chosen as opposed to all publications, as top publications more accurately measure quality research being done at a university or college. Faculty who publish in top journals also have qualities I want to account for, such as extensive professional networks and a commitment to research. I expect both faculty variables to have a positive effect on the rate of S&E doctoral degrees produced.

Exposure to research may also depend upon the location of the institution and its physical proximity to other research institutions. Dummy variables for suburban and urban campuses will be used to test this for this. It is likely that urban institutions will have greater geographical access to nearby research facilities, so I expect the sign for the urban dummy to be positive.

At the student level, the decision to pursue a PhD is hypothesized to be positively related to ability. There are a number of ability measures to choose from: high school rank, standardized test scores, and AP placement rates, all of which are aggregated at the institution level. For degrees in math and science, especially in the non-biological sciences, one would expect a particularly strong relationship between math scores and the decision to pursue a PhD. Taken together, these ability measures are also indicators of peer quality, and will be used as proxies for peer effects. Thus, it is difficult to differentiate between peer effects versus ability factors.

I also hypothesize that international students have a higher rate of PhD attendance than citizens based on the assumption that international students coming to the United States for undergraduate education have the intention of remaining in the country for graduate school. Finally, I control for the number of non-white, non-Asian minority students on campus, given the evidence that they have a lower rate of attending graduate school.[44]

As discussed in Chapter 3, other variables also matter. For example, economic conditions at the time of BA graduation have been shown to impact doctoral attainment: higher unemployment rates drive more students to apply for graduate school (something we are seeing in today's economy[45]). Likewise, increases in graduate stipends have been shown to increase the rate of students entering PhD programs. While individual school stipend data are not available, they have been shown to follow a pattern of the NSF Graduate Research Fellowship Program stipends. Although these NSF stipends vary over time, they are typically invariant by institution and thus reflect macro conditions for graduate students. Because of this and the difficulty in obtaining data on institution-granted stipends for individual schools, I assume stipends move with NSF levels across all institutions.

For the analysis, I divide institutions into the "tiers" shown in Table 4.1. Distribution of the tiers, and distribution of the raw number PhDs produced by each tier, is shown in Figure 4.1. Table 4.2a summarizes the dependent variable (S&E PhDs per 1000 enrolled students) by tier and by whether the sample is restricted to institutions producing one or more PhD. It should be noted that these rates are considerably lower than those reported by Burrelli et al. because, as discussed above, they use a denominator equal to degrees (i.e., graduates) in science and engineering, while those presented here use a denominator equal to total undergraduate enrollment. As

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[44] Asian students have a much higher rate of PhD attainment than do other minority students.

[45] While graduate applications have increased during the most recent recession, graduate school enrollments are down. This is due to both the cost of graduate school and, for those with a job, the risk a job will not be there when they graduate (Lewin 2011), as well as the limited student slots available due to constraints on graduate program staffing and funds.

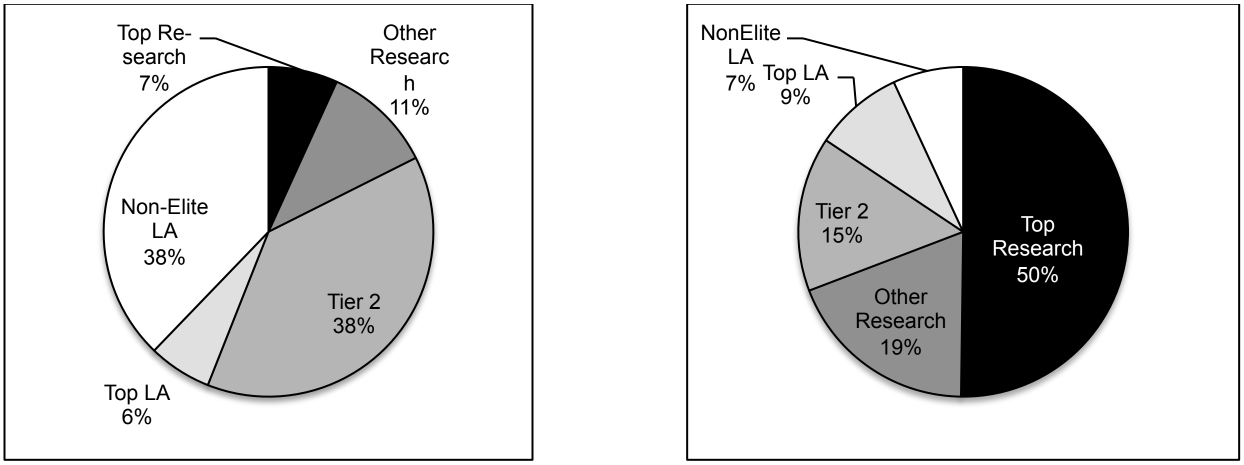
expected, the highest rates are observed at top liberal arts colleges (4.86 for all observations), followed closely by Top Research at 4.32. The Other Research is considerably lower. The lowest level of productivity is observed at Tier 2.

Table 4.1: Institution Tiers

Tier	Description	Carnegie (1994) Classification
Top Research	Top research focused, PhD-granting	11, 12
Other Research	Research-focused, PhD-granting	13, 14
Tier 2	Master's-granting	21, 22
Top Liberal Arts (LA)	Top institutions where less than half of degrees awarded are MA, MS or PhD. Comprehensive curriculum in undergrad.	31
Non-Elite Liberal Arts (LA)	Less than half of degrees awarded are MA, MS or PhD. Comprehensive curriculum in undergrad.	32

Source: Carnegie Foundation

Figure 4.1: Distribution of Institutions and PhDs across Tiers



Institutions by Tier

PhDs by Tier

The independent variables discussed above are summarized in Table 4.2b and visually in Figures 4.2, 4.3, 4.4 and 4.5. I have good, mostly complete measures for these variables across years and school types. Observations are equal to the number of BA-year lines of data. There are 1273 institutions and 13 years (1990-2002), which provides 16,549 lines of data. Some of the College Board variables are incomplete for certain years, which is reflected by a lower number of observations in the table.

Table 4.2a PhDs per 1000 students: Zero and Non-Zero Observations by Tier

	All	Top Research	Other Research	Tier 2	Top LA	Non-Elite LA
Rate of all observations	1.25	4.32	1.51	0.52	4.86	0.78
Observations with rate = 0	5,949	8	103	2,233	68	3,537
Percent observations with rate=0	35.9%	0.7%	5.78%	35.1%	6.6%	56.4%
Rate of observations with rate>0	1.95	4.35	1.60	.80	5.20	1.79

The data show considerable variation by institution type. For example, almost 50% of the student body at Top Research and Top Liberal Arts colleges comes from the top 10% of their High School class, compared to only 20% for the Non-Elite Liberal Arts. SAT scores (at both the 75% and 25% cutoff) are highest for students at Top Liberal Arts Colleges. It is also notable that the Verbal SAT score of those at the 25th percent are higher at top liberal arts colleges than the SAT scores of those in the 75th percentile in all other institutions save Top Research; Math SAT scores at the 25th percent are higher at Top Liberal Arts Colleges than math SAT scores at the 75th percent for the Non-Elite Liberal Arts and Tier 2. Faculty top publications are highest at Top Research institutions; and virtually non-existent at the Non-Elite Liberal Arts. The percent of faculty with a PhD varies from about two in three at Top Liberal Arts Colleges and Top

Research institutions to less than one in four for the Non-Elite Liberal Arts. Top Liberal Arts colleges have the highest percent of students in college housing by far.

There are student characteristics that I cannot control for, however, such as attitudes toward graduate school, family expectations, preferences of the students, etc. Using the HERI data, I can form some measures of these variables for different types of institutions. As noted above, HERI stratifies their data over 21 school types (based on public/private, religious/nonsectarian, and selectivity[46]).

Figures 4.6, 4.7 and 4.8 present visual representations of the summary statistics. Table 4.2c presents the variables I will employ from the HERI dataset, as well as what they are intended to proxy and the hypothesized signs for impact on S&E PhD rates. These data are for one year (freshman year of 1993 and senior year of 1996), so they do not vary over time but do vary over the type of institution. Given this limitation, in the final part of the analysis, I run the model for one year only (1996) to get an accurate picture of how the individual-level variables impact PhD output. I will run the HERI variables alone for 1996, and then run the full model (again only for 1996), adding in these new variables for controls.

The HERI summary statistics presented in Figures 4.6-4.9 present information on how selection might vary between institution type. For example, the average student at a liberal arts institution is likely to have a father with more education than his or her mother; while at research and Tier 2 institutions, mother’s education is likely to be

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[46] This is measured by an SAT score range for incoming freshman classes.

Figure 4.2a: HS Rank Ability Measures (Means)

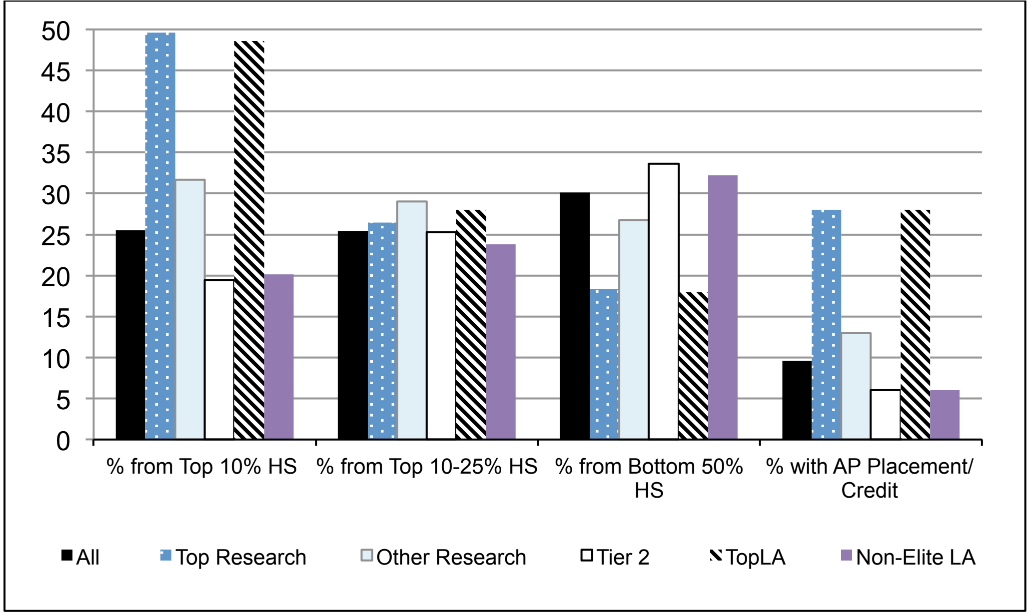

Figure 4.2b: SAT Ability Measures (Means)

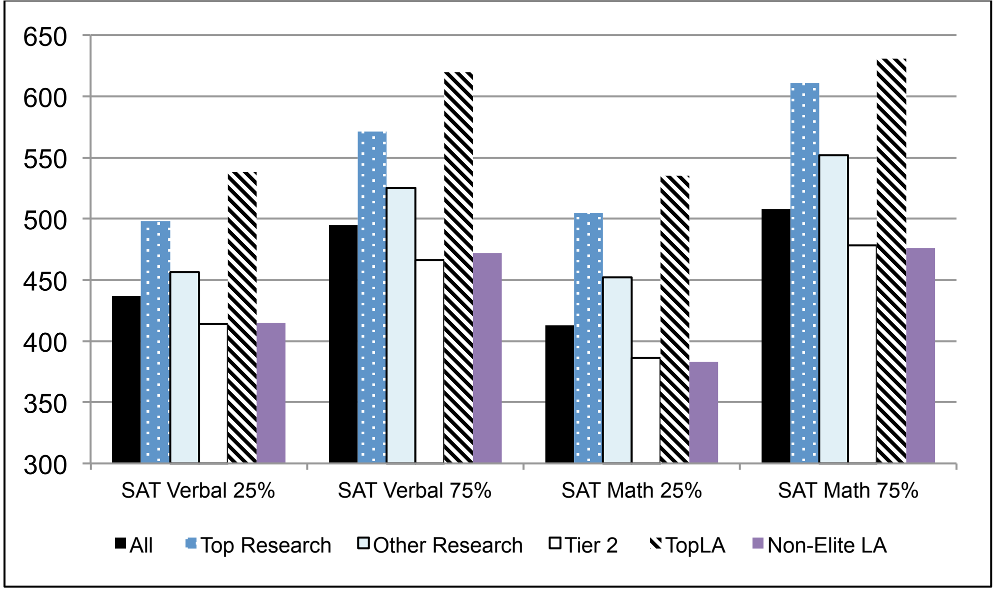

Figure 4.3: Faculty Statistics (Means)

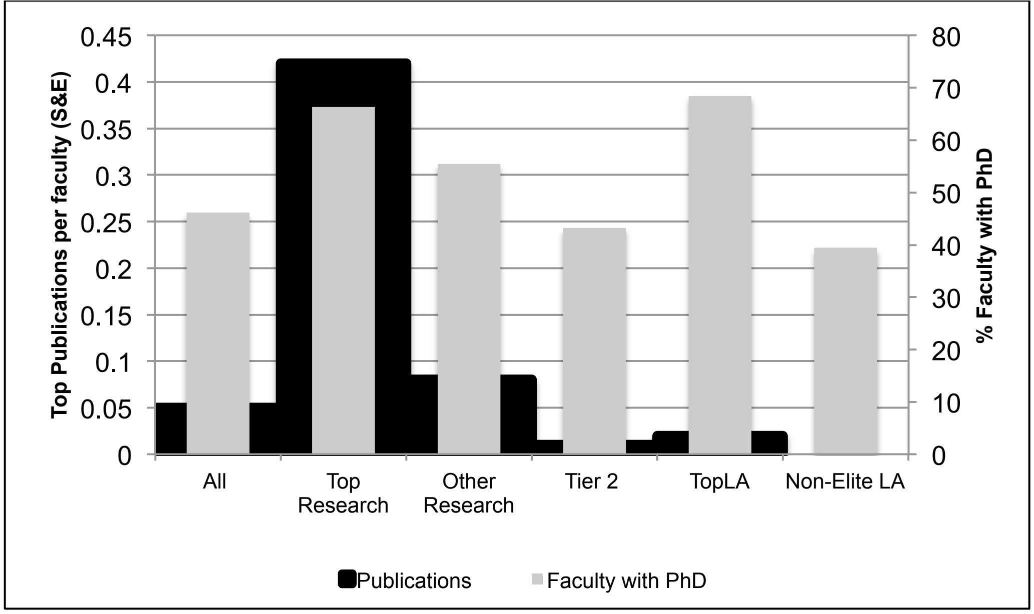

Figure 4.4: Peer Effects (Means)

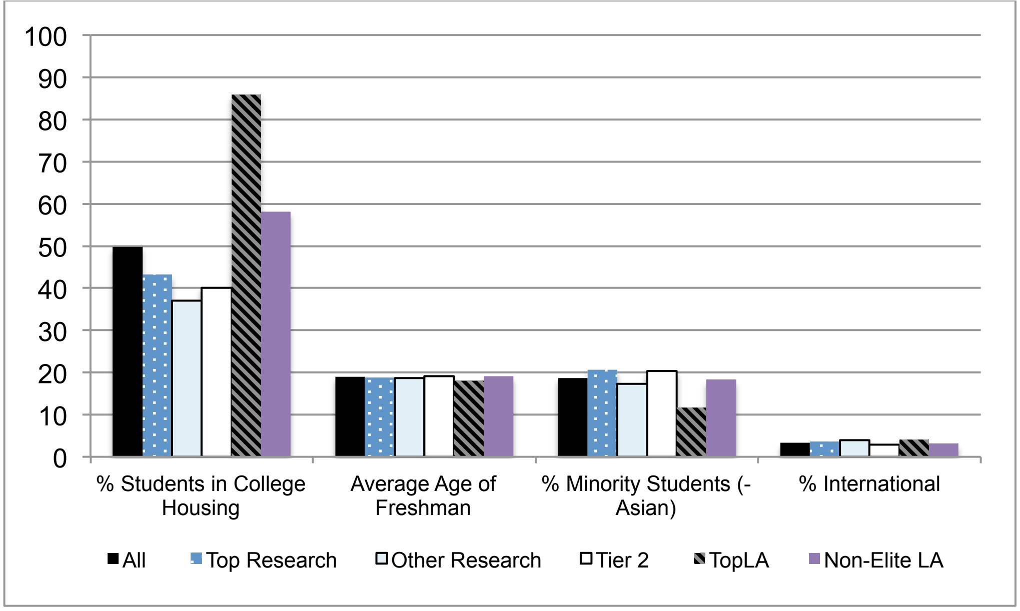

Figure 4.5: Location of Campus, by Tier

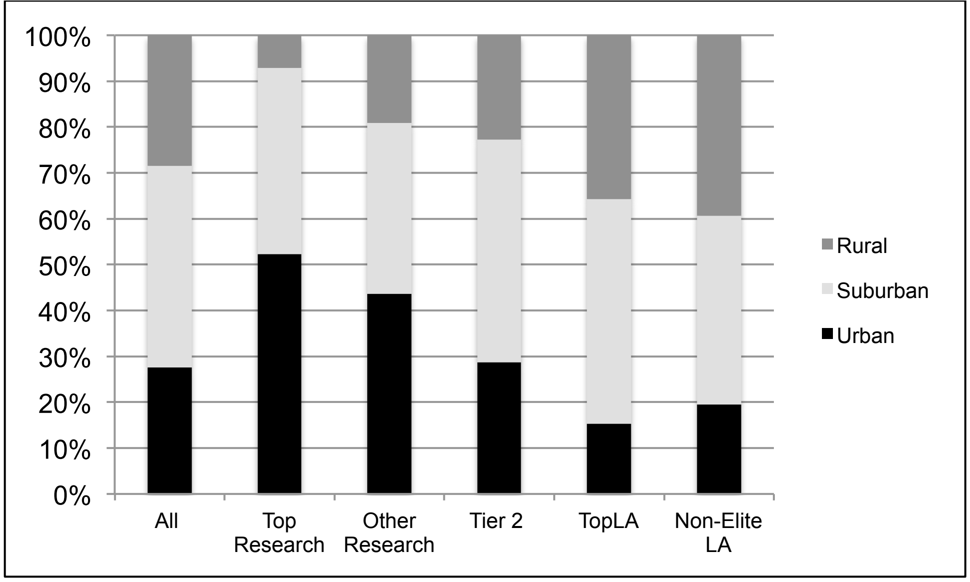

Table 4.2b: Independent Variables and Expected Signs

Variable	Proxy for	Expected Sign	Obs
% Students in top 10% HS	Ability & Student Characteristics	+	13438
% Students in top 10-25% HS		+	13330
% Students in bottom 50% HS		-	13760
SAT Verbal 25th percentile		+	12265
SAT Verbal 75th percentile		+	13151
SAT Math 25th percentile		+	13139
SAT Math 75th percentile		+	13139
% Students w/ AP Place/Credit		+	14137
Top Publications per faculty (S&E)	Exposure to Research & Faculty Reputation	+	14001
% Faculty w/ PhD		+	16311
% Students in College Housing	Peer Effects	+	15696
Average Age of Freshman		-	16167
% Minority Students (- Asian)		-	16493
% International		+	16050
Urban	Exposure to Research	+	16549
Suburban		+/-	16549
Unemployment Rate (State; Mean = 5.33)	Economic Conditions	+	16460
NSF Stipend/Wage Ratio*100 (Mean = 85.31)	Economic Conditions & Cost of Training	+	16460

Figure 4.6: Parents’ Education, by Tier

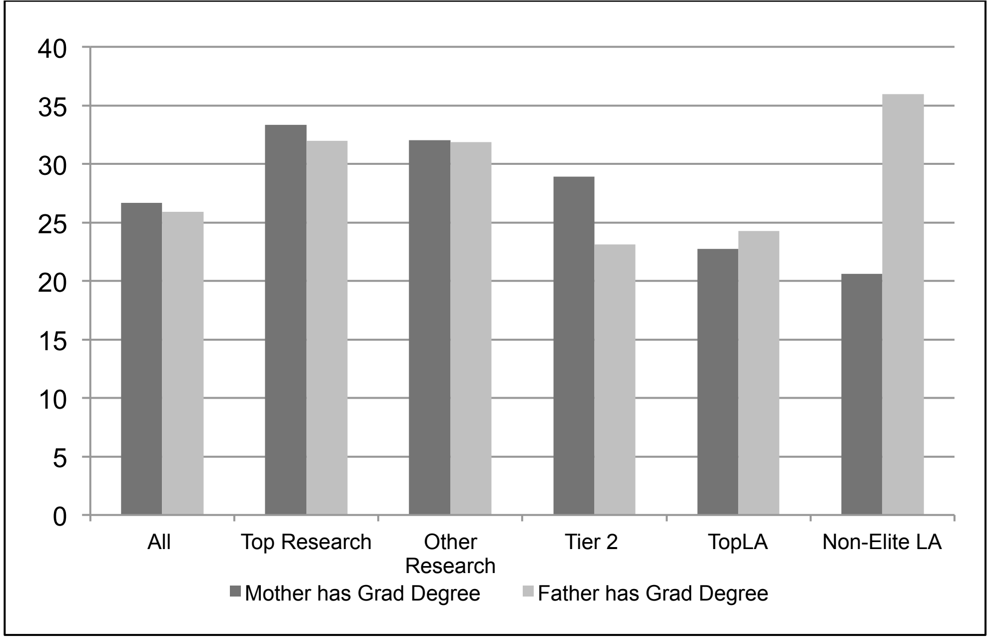

Figure 4.7: Intentions for PhD

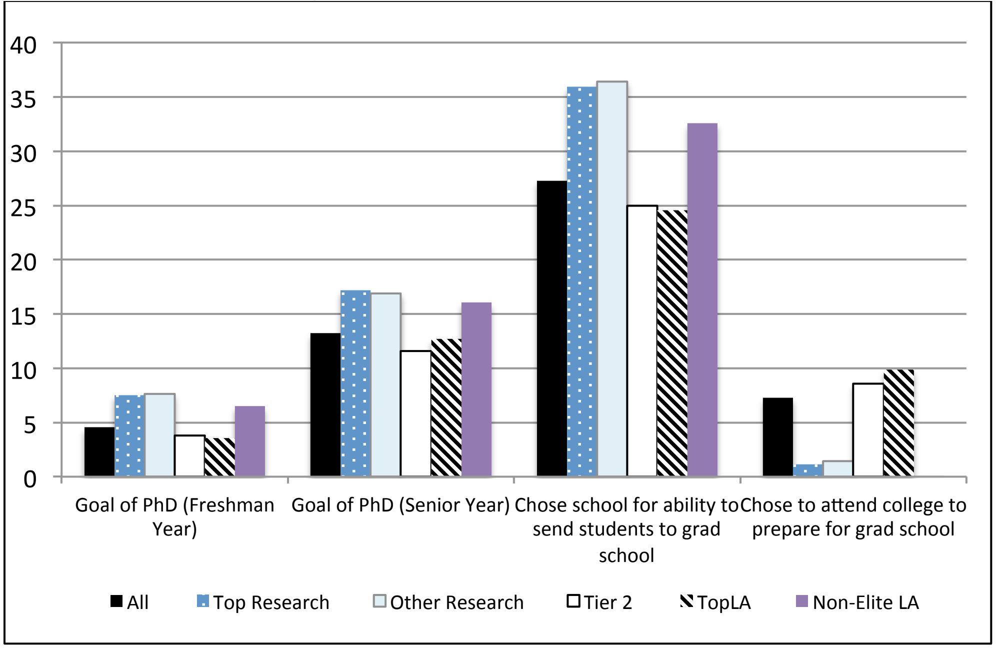

Figure 4.8: Exposure to Research (Proxies)

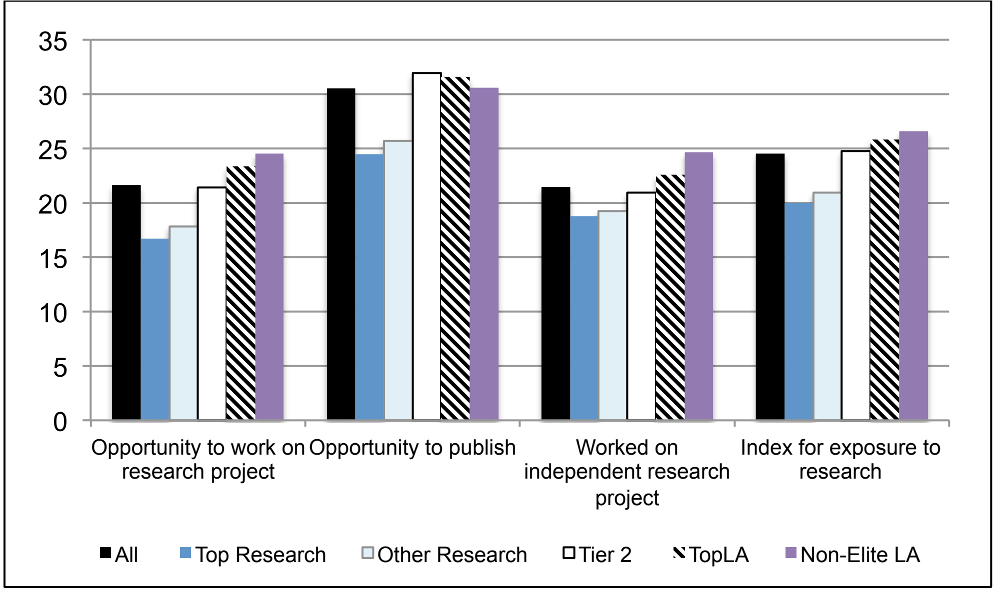

Figure 4.9: Faculty's Role (Proxies)

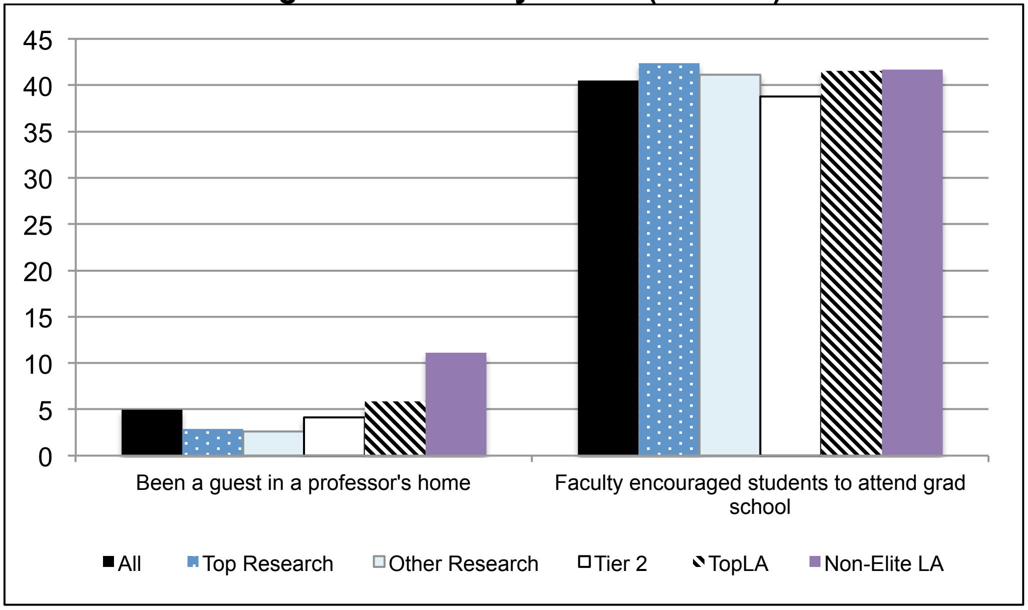

Table 4.2c: HERI Summary Statistics

Variable	Proxy for	Expected Sign	Obs
Mother has Grad Degree	Expectations	+	16528
Father has Grad Degree		+	16528
Mother or Father has Grad Degree		+	16528
Goal of PhD (Freshman Year)	Plans for PhD (Selection)	+	16528
Goal of PhD (Senior Year)		+	16528
Chose school for ability to send students to grad school		+	16528
Chose to attend college to prepare for grad school[47]		+	16528
Faculty encouraged students to attend grad school	Influence of Institution	+	16528
Opportunity to work on research project	Exposure to Research	+	16528
Opportunity to publish		+	16528
Worked on independent research project		+	16528
Index for exposure to research		+	16528
Been a guest in a professor's home	Pos. Association w/ PhD Life	+	16528

slightly higher. Figure 4.7 presents graduate school goals of the student. What stands out are the high percentages of students at non-elite liberal arts institutions who have more ambitious goals of a PhD than their peers at top liberal arts institutions. However, attending college for the purpose of preparing for graduate school was an almost nonexistent response from this group. As expected, students attending research institutions have the highest ambitions for earning a PhD.

Figure 4.8 shows research exposure at each type of institution. The final variable is an index of the first three. It is clear, at least from this survey and for certain measures, that liberal arts institutions provide more research opportunities to their students. Figure 4.9 presents faculty influence. Students at a non-elite liberal arts institution are almost three times as likely to have been a guest in a professor’s home,

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[47] This and the variable directly above are similar, but the questions are phrased very differently in the actual survey. For the first variable, the question reads,: “Below are some reasons that might have influenced your decision to attend this particular college. How important was each reason in your decision to come here?” This variable reflects the percentage of students who answered “Very Important” (as opposed to “Somewhat Important” or “Not Very Important”) to the option “This college’s graduates gain admission to top graduate/professional schools.” The second variable’s question: “In deciding to go to college, how important to you was each of the following reasons?” This reflects the percentage answering “Very Important” to the response “To prepare myself for graduate/professional school.”

with non-elite research institutions having the lowest average for this metric. Encouragement for graduate school was not only relatively constant across institution type, but is also surprisingly high, at around forty percent.

Econometric Challenges

Three main econometric challenges arise in estimating the reduced form models. The first is that the dependent variable is censored at zero, representing years in which a school produces no PhDs.[48] Moreover, there are a large number of zeros since the majority of institutions rarely send students on to get a PhD.

The following figure shows the percentage of institutions each year that produced zero S&E PhDs by tier. As can be seen, the percent of Top Research institutions producing no PhDs is at or near zero percent (as expected), meaning close to 100% of these schools have produced an S&E PhD for each of the BA classes from 1990 through 2002. The percent of Other Research and Top Liberal Arts institutions producing no PhDs is relatively consistent over time, with a spike at the end, reflecting the downturn because of shortened available time frames for graduate study. What is interesting is that the percent of institutions producing no PhDs in both Tier 2 and the Non-Elite Liberal Arts declines considerably over time, despite the countervailing force for the percent to increase due to the censored nature of the data. This suggests the interesting finding that the pool of BA institutions sending individuals on to get a PhD

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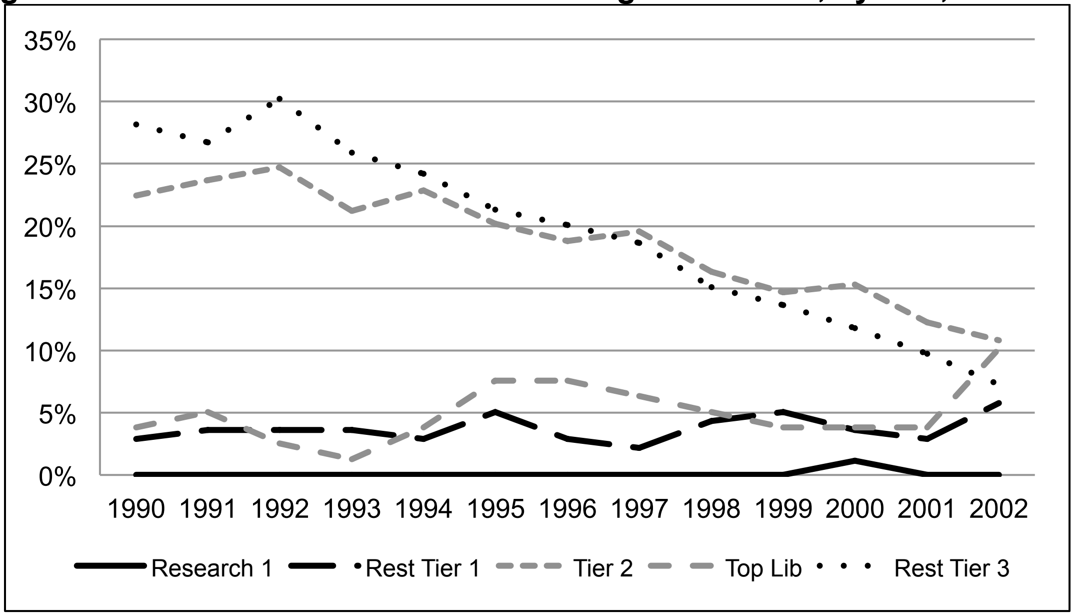
[48] Theoretically, the data are also censored at one. However, the highest rate of PhD output observed in the data is 42 per 1000 students. Thus, the upper bound is not an issue.

has grown over time and become more diverse. The censoring issue can be addressed using a Tobit, model, imposing a lower bound of zero.[49]

Figure 4.10: Percent of Zero-PhD Producing Institutions, by Tier, 1990-2002



The second econometric problem involves selection bias related to institutions. There are over 2100 accredited BA-granting institutions in the United States. There are another 1000 community colleges.[50] As noted in the above discussion, by definition, only schools that have produced at least one PhD in S&E between 1990 and 2002 are included in the analysis.

Drawing on the SED, I find 1523 institutions that produced one or more PhDs during the time period. I eliminated an additional 250 of them because we did not have publication data for these institutions. This could be due either to the institution not publishing at all, or to the fact that the institution was fairly recently established or

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[49] The Tobit model assumes there is a cluster of observations at the lower, or upper bound (in this case, it is the lower).

[50] Web U.S. Higher Education, University of Texas

reorganized and thus not included in the list of U.S. institutions compiled for the Levin et al. study. This leaves 1273 institutions.

Selecting institutions in this manner could lead to biased results if publishing is correlated with factors that affect the PhD rate. There are two possible approaches to addressing this issue. First, one could use a Heckman model to try to correct for selection bias, but this is not feasible given the complexity of selection based on student and institution attributes and a paucity of data available to model such selection. A second adopts a policy approach to address the problem of omitting certain schools from the data set. I take the latter approach here.

From a policy perspective, is it unrealistic to assume the types of institutions omitted from my dataset include "PhD output" in their objective function, or that federal aid is expected to increase the output of doctoral students coming out of these schools. The majority of these schools have an entirely different objective function than institutions that publish articles and produce graduate students. There may be a few schools trying to break into the graduate student market, but most – such as community colleges and online institutions – cater to a very different market.[51] Stated alternatively, we estimate institutional PhD output for the population of colleges and universities for which this activity has some degree of relevance.

A third econometric challenge is the issue of whether institutional effects can be distinguished from individual effects; that is, certain institutions may attract individuals already committed to going to graduate school and, if the preferences and abilities of these individuals are not controlled for, these institutions' propensity for sending

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[51] A few institutions, however - such as Harvey Mudd - produce a large number of PhDs but were not included in the publication database because of their relatively young age.

individuals on to graduate school will be overstated. While we have certain data, such as SAT scores and rank in high school class, that allow us to control for some types of selection effects, we do not have data on students' intentions at the time they come to college. In order to address such selection issues, we employ the HERI data on students, which allows us to measure to what extent students are predetermined to get a PhD.

The HERI data, however, produce a related challenge in the sense that it is only available for one time period. Moreover, the data are only available by institution type rather than at the individual institutional level, so much of the variation is lost, especially when school-type dummies are included in the analysis. Moreover, the survey responses are a small subset of the total student population (because institution identifiers are hidden, I cannot calculate the percentage response rate – but I know from observations that it is low). Because of the large number of institutions, and relatively few students surveyed within each, I use clustered standard errors by institution to provide appropriate standard errors.

Thus, I have two options in utilizing the HERI data: (1) apply the proxies based on school stratification (one of twenty-one institution types) for each year, or (2) use only the 1996 BA-year data (the year of the HERI Senior Survey). The former option has a bit of variation by institution over time, because, as noted above, schools can move into more (or less) selective stratifications based on average SAT scores of incoming freshman over time. However, schools are not fundamentally different just because they moved from one category to the next (e.g., it is unlikely that a school whose students average 1190 on the SATs operate significantly differently from one with students averaging 1200), so the focus will be on the latter option. This should give a “snapshot” of what is driving PhD output within an institution, but a lot of explanatory power is lost by removing 12 years of data.

The fact that the HERI data are available for only one year means that if the data are used to estimate the model over the entire time period the only variation over time comes when an institution moves to another stratification, due either to its SAT score rising or falling substantially. However, most institutions remain in the same stratification for all years. For differing stratifications, the data show drastic differences in graduate school goals, parents’ education levels, reasons for choosing to attend college, and opportunities while an undergraduate. If it is reasonable to believe that certain types of students consistently choose similar institutions over time - and that these patterns hold over time - we can use these variables as proxies for traditionally “un-measureable” variables. However, they are highly correlated with type of institution as well as a number of the College Board variables.

To summarize, I will start with the basic model for years 1990-2002, which includes variables that measure type of institution and controls for time trend. I will then add variables measuring economic conditions, and finally institutional variables and student variables. Next I will estimate the model by type of institution and by field of degree. Finally, and for one year, I will use the HERI data to try to get a better understanding of the issue of selection.

Estimations

As noted above, I use a Tobit regression model because the dependent variable, the rate of PhD output, is left-censored at zero. To present a simplified model, consider the dependent variable, P_t, as a function of ability (Avg. GPA of freshman) and exposure to research (publications per faculty member).

$$P_t^* = \beta_1 * GPA + \beta_2 * pubs + error$$

To simplify, let X be a matrix of GPA and publications:

$$P_t^* = X_t \beta + error$$

P_t* is a latent variable that is observed for values greater than zero and censored otherwise. Observed *P* is defined by:

$$P_t = \begin{cases} P^* \; if \; P^* > 0 \\ 0 \; if \; P^* \leq 0 \end{cases}$$

The basic coefficients resulting from the Tobit regression are of little use; they are simply the marginal effect on the latent variable. Taking the log likelihood function, however, for this model, we get two parts. One part reflects the probability that an observation is not censored at zero; the other part reflects the uncensored observations, where the rate P_t is greater than zero.[52]

From these two parts three marginal effects, as noted earlier, can be computed: first, the change in the probability that the right hand side variable will fall within the uncensored range—that is, the probability that a non-producing institution will produce one or more PhDs in a given year. Second, the change in the conditional mean of the dependent variable due to a change in the right hand side variable; this result is the marginal effect of a variable on the productivity rate given that the rate is non-zero. Third, we can show the change in the unconditional mean of the PhD output rate due to

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[52] These two values are estimated using the McDonald Moffitt (1980) decomposition. This decomposition shows that a change in the right hand side variables not only affects the conditional mean of the PhD output rate, but also affects the probability that an observation will be within the censored values (i.e., between zero and one hundred percent).

a change in the independent variables.[53] This is a combined effect of the first two. By way of example, an increase in a positively correlated independent variable will result in some non-producing institutions moving to positive production while others will produce at a higher rate.

Which type of marginal effect should be reported? Per Greene (2003) and Wooldridge (2002), if the data are always censored, the basic coefficients, reflecting the effect of a variable on the latent dependent variable, are not very informative, as mentioned above. The probability effect is useful when some observations are censored, as it gives an indication of the effect of a variable on movement from zero to positive rates. The second effect is useful if we are only interested in the uncensored observations, which, in my case, is any school with a positive PhD rate. The third combines the two effects. Because there are schools with a rate of zero for some years but not others, it's reasonable to assume that certain explanatory variables have an effect on the probability that an institution will output any PhDs (i.e., an increase of research exposure can pull a school up from zero to a positive rate of PhD output) as well as an additional effect conditional on institutions outputting PhDs. Therefore, the first is relevant when these types of institutions are included; the second is most relevant for the class of institutions that almost invariably output PhDs (e.g., Top Research institutions), although it is also interesting to know if, in classes of institutions that rarely output PhDs the marginal effects vary conditional on their outputting one or more PhDs. The third is relevant in the sense that it combines the first two. For

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[53] These marginal effects are reported as (1), (2) and (3), respectively, in the tables below.

institutions that almost invariably output PhDs, the second and third will be almost identical. I present all three effects below.

The following estimates of PhD output employ a panel Tobit model for the years 1990-2002, where year refers to the year of BA graduation, and institutions are categorized by tier (as described in Table 4.1). Each set of Tobit results is defined by the independent variables included, followed by the output table and a brief discussion of the results.

The dependent variable, as noted above, is defined in terms of the number of PhDs output per 1000 students. The mean for the uncensored sample is 1.25 and for the censored sample is 1.95. Most independent variables are expressed in percentage points, although there are certain exceptions (see Table 4.2).

School Type and Time Trends

The first estimation presented in table 4.3 is the school-level PhD output rate regressed on school type and time. Several papers and reports have focused on this type of estimation, examining how the type of school is related to the rate of PhD output. For example, in the NSF InfoBrief “Baccalaureate Origins of S&E Doctoral Recipients,” Burrelli, Rapoport, and Lehming find for 1996-2005 that top liberal arts schools output at the highest rate (between five and six percent), while research universities output just under half of the total number of S&E doctorates. In the specification presented below, the omitted category is the Non-Elite Liberal Arts (i.e., other liberal arts schools (non-elite)) and 1990. The Tobit results presented are the three marginal effects of the expected value of the dependent variable (discussed above).

Table 4.3: Marginal Effects: School Type and Year, 1990-2002[54]

	(1)	(2)	(3)
		Mean rate = 1.95	Mean rate = 1.25
Top Research	**0.435******	**2.932******	**3.804******
	(0.012)	(0.222)	(0.251)
Other Research	**0.241******	**0.879******	**1.241******
	(0.025)	(0.123)	(0.170)
Tier 2	**0.044*****	**0.124*****	**0.176*****
	(0.021)	(0.062)	(0.087)
Top Liberal Arts	**0.447******	**3.346******	**4.266******
	(0.011)	(0.240)	(0.264)
1991	0.005	0.015	0.021
	(0.010)	(0.027)	(0.038)
1992	0.004	0.011	0.016
	(0.010)	(0.027)	(0.038)
1993	-0.014	-0.038	-0.054
	(0.010)	(0.026)	(0.037)
1994	**-0.027******	**-0.075******	**-0.106******
	(0.010)	(0.026)	(0.037)
1995	0.001	0.002	0.002
	(0.010)	(0.027)	(0.038)
1996	**-0.028******	**-0.078******	**-0.110******
	(0.010)	(0.026)	(0.037)
1997	**-0.026******	**-0.070******	**-0.099******
	(0.010)	(0.026)	(0.037)
1998	**-0.034******	**-0.092******	**-0.130******
	(0.010)	(0.026)	(0.036)
1999	**-0.051******	**-0.136******	**-0.192******
	(0.010)	(0.025)	(0.036)
2000	**-0.075******	**-0.199******	**-0.279******
	(0.010)	(0.025)	(0.035)
2001	**-0.119******	**-0.306******	**-0.426******
	(0.010)	(0.024)	(0.033)
2002	**-0.211******	**-0.516******	**-0.703******
	(0.010)	(0.023)	(0.031)
Observations		16,549	
Institutions		1,273	

Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

The rate of S&E PhD output, as expected, is significantly related to the school type in all cases. Relative to the benchmark group (Non-Elite Liberal Arts), all other

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[54] Censored observations: 35.9%, Uncensored: 64.1%. Omitted Tier: Non-Elite LA; Omitted Year: 1990. (1) summarizes the effect on the probability that an institution is not censored. (2) summarizes the effect on the rate given that an institution is not censored. (3) summarizes the combined effect of a producing institution generating more PhDs plus the effect of a non-producing institution becoming a producing institution (or, in the case of a negative effect, a producing institution either producing less or moving to non-PhD output status).

school types produce at a higher rate, with Top Research and Top Liberal Arts being the highest producing.

Consider the first column: this shows the marginal effects on the probability that an institution in a particular year is not censored, that is, the probability that it produces one or more PhD students. Clearly tier matters. These results have signs and levels of significance that are intuitively what we would expect (i.e., Top Research and Top Liberal Arts have high positive and significant marginal effects compared to Non-Elite Liberal Arts; Other Research has less of a positive effect on the probability, and Tier 2 has the lowest effect on the probability).

The second column gives the effect of the independent variables on the production rate, conditional upon the institution being a producer of PhDs. (In this case, the mean rate for institutions that actually produce at least one PhD is 1.95.) The marginal effect of being a Top Research institution is 2.932[55], or, relative to the mean, an estimated increase in PhD output of 150%; top Liberal Arts colleges have a rate that is 3.346 above that of the benchmark, or an estimated172% above the mean.

Finally, column (3) tells us the increase (or decrease) from two combined effects: first, the effect of greater (or less) production of schools that are already producers, and second, the increase in production by schools moving from zero PhDs to positive PhD output. After controlling for time effects, being a Top Research school translates into an increase of production of 3.8 S&E PhDs per 1000 students - an increase that is 300 percent above the mean of 1.25 per 1000. Being a Tier 2 institution has a much lower

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[55] These coefficients on categorical variables should be compared to the “base” or omitted category, which in this case is Non-Elite LA and the year 1990. The coefficient here, therefore, can be assumed to reflect what was happening in the first year in the dataset. Considering later years, this effect will decrease, as the rate becomes smaller over time because it cannot capture eventual PhDs (or those who graduated/will graduate after 2008).

effect, with an increase of .176 PhDs per 1000, or an increase of just over 14% of the mean; being a Top Liberal Arts institution increases production by 4.66 PhDs per thousand students (an increase of almost 400 percent above the mean).

The year dummies indicate the time trend. We expect the later years to be negative due to the tapering off of students into the PhD pipeline. While the mean time from BA to PhD is nine years, many students take longer. We see this in the increasingly more negative marginal effects as time goes forward. Although not shown in tables that follow, variation over time is controlled for in these estimations in the same manner. In addition to year-specific effects, the dummies capture the tapering off of rates due to the shorter windows of time in which to observe whether a PhD is completed.

It is worth noting that in Table 4.3 - and in subsequent tables estimates using the McDonald Moffitt decomposition – effects indicate that most of the action is on the internal margin (column 2) and not the external margin (column 3). In other words, the majority of the effect is captured by an increase in already-producing institutions; while the movement of schools from non-producers to producing status exists, the effect is generally small compared to increases in production from institutions already generating S&E PhDs.

The second estimation includes school type dummy variables as before, and adds variables reflecting economic conditions. Because a significant majority of college graduates remain in the state where they attend undergraduate school,[56] I use state

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[56] 70%, according to Kodrzycki (2001)

unemployment rates for the year prior to graduation.[57] The unemployment rate varies greatly between states, so this variable should capture a more accurate picture of the influence the economy has on the decision to obtain work or begin graduate school. The NSF stipend amount, relative to starting salaries for S&E majors out of undergrad, is also added to measure potential income and/or the cost of training for graduate students.

Table 4.4: Marginal Effects: Economic Factors and Year/Tier Indicators, 1990-2002[58]

	(1)	(2)	(3)
		Rate mean = 1.95	Rate mean =.1.25
State Unemployment Rate	**0.006****	**0.018****	**0.026****
	(0.003)	(0.008)	(0.012)
NSF Stipend/Wage	**0.006*****	**0.018*****	**0.025*****
	(0.000)	(0.001)	(0.001)
Top Research	**0.434*****	**2.920*****	**3.791*****
	(0.012)	(0.222)	(0.252)
Other Research	**0.239*****	**0.872*****	**1.232*****
	(0.025)	(0.123)	(0.170)
Tier 2	**0.043****	**0.122****	**0.172****
	(0.021)	(0.062)	(0.088)
Top Liberal Arts	**0.446*****	**3.338*****	**4.257*****
	(0.011)	(0.240)	(0.264)
Observations		16,549	
Institutions		1,273	

Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

The marginal effect of the state-level unemployment rate is positive and significant, as expected (i.e., as the unemployment rate goes up, doctoral productivity

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[57] A study by Lisa Kahn found that for each percentage point increase in the unemployment rate (national), new graduates suffer a 6-7% decrease in initial wages. Graduates are forced to take lower paying jobs and they stay in them longer, affecting the chance of upward mobility. (2009)

[58] Censored observations = 35.9%, Uncensored observations = 64.1%. Omitted Tier: Non-Elite LA. (1) summarizes the effect on the probability that an institution is not censored. (2) summarizes the effect on the rate given that an institution is not censored. (3) summarizes the combined effect of a producing institution generating more PhDs plus the effect of a non-producing institution becoming a producing institution (or, in the case of a negative effect, a producing institution either producing less or moving to non-PhD output status).

increases), although the effect is small. Focusing on the marginal unconditional effects reported in column (3), we see that for every percentage point increase in unemployment, the productivity rate increases by about 2.1% of the mean. PhD output is also significantly related to the relative NSF stipend level. As the NSF stipend increases relative to average starting salaries, PhD output slightly increases. To be more specific, increasing graduate stipends by one percent as compared to average salaries increases the unconditional PhD output rate by .025 per 1000, just over 2% of the mean rate. It should also be noted that adding in the economic indicator variables leads to minimal change in the school-tier marginal effects, although both economic indicator variables are significant.

Ability, Exposure to Research, Peer Effects, and Economic Variables

The next set of regressions focuses on variables measuring characteristics of students that I expect to have an impact on the output of PhDs: ability of students (using three different measures: distribution of students' high school standing, percent taking AP classes in high school, and average SAT scores) the percent of international students and the percent of minority students. Institutional variables are also included, measuring exposure to research (top publications per faculty member and percent of faculty with a PhD) and peer effects (percent of students in college housing and the average age of freshmen students).

The results in Table 4.5(a-c) are presented in three distinct panels, representing three alternative measures of ability. The equations are estimated in this manner given the high level of collinearity among the ability variables.

Regardless of measure, ability, as hypothesized, matters and is significant at the one percent level, relating not only to the level of productivity but also to whether an institution produces one or more PhDs. In terms of the unconditional marginal effects, institutions that have a higher percent of students coming from the top 10% of their high school class produce more PhDs. For every one percentage point increase, they send an increase of .033 students per 1000 on to get a PhD. Institutions that have a higher percent taking AP classes in high school have a higher rate, sending 1.458 more students on for each percent increase in those with AP credit. Institutions that draw

Table 4.5a: Student and Faculty Characteristics (HS Rank), All Tiers, 1990-2002[59]

	(1)a	(2)a	(3)a
	Panel 1: HS Rank		
% Freshman top 10% HS	**0.008*****	**0.023*****	**0.033*****
	(0.001)	(0.002)	(0.002)
% Freshman top 10-25% HS	**0.002*****	**0.005*****	**0.008*****
	(0.001)	(0.002)	(0.002)
% Freshman Bottom 50% HS	0.001	0.002	0.003
	(0.001)	(0.002)	(0.003)
Top S&E Pubs per faculty	**0.384*****	**1.055*****	**1.505*****
	(0.060)	(0.164)	(0.234)
% FT Faculty With PhD	**0.003*****	**0.008*****	**0.011*****
	(0.000)	(0.001)	(0.001)
% Students in College housing	**0.002*****	**0.004*****	**0.006*****
	(0.000)	(0.001)	(0.001)
Average Age of freshman	-0.001	-0.003	-0.004
	(0.002)	(0.005)	(0.007)
% Minority (- Asian)	**-0.001****	**-0.003****	**-0.005****
	(0.000)	(0.001)	(0.002)
% International	0.000	0.001	0.002
	(0.001)	(0.004)	(0.005)
Urban	0.000	0.000	0.000
	(0.000)	(0.001)	(0.001)
Suburban	-0.000	-0.000	-0.001
	(0.000)	(0.000)	(0.001)
State Unemp, Rate	**0.011*****	**0.031*****	**0.044*****
	(0.004)	(0.011)	(0.016)
NSF Stipend to Wage Ratio	**-0.021*****	**-0.058*****	**-0.083*****
	(0.002)	(0.006)	(0.009)
Observations		10,594	
Institutions		1,022	

Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

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[59] Panel 1 censored: 31.3%, uncensored: 68.7% (mean rate = 2.04, overall mean rate = 1.40). Panel 2 censored: 32%, uncensored: 68% (mean rate = 1.98, overall mean rate = 1.34). Panel 3 censored: 30%, uncensored: 70% (mean rate = 2.15, overall mean rate = 1.51).

students with higher SAT scores have a significantly higher rate of PhD output with one exception: Institutions with high verbal scores send fewer students on to get a PhD in science and engineering. While initially counterintuitive, it is feasible that institutions attracting very high performing language arts and humanities students are less likely to output a high number of S&E PhDs. Perhaps there is nothing that can be done to convince these students to enter a field of S&E.

Table 4.5b: Student and Faculty Characteristics (AP Placement), All Tiers, 1990-2002[60]

	(1)b	(2)b	(3)b
	Panel 2: AP Placement Rates		
% Freshman	**0.366*** **	**1.023*** **	**1.458*** **
Taking AP in HS	(0.048)	(0.130)	(0.186)
Top S&E Pubs	**0.516*** **	**1.441*** **	**2.054*** **
per faculty	(0.067)	(0.182)	(0.260)
% FT Faculty	**0.003*** **	**0.008*** **	**0.011*** **
With PhD	(0.000)	(0.001)	(0.001)
% Students in	**0.002*** **	**0.005*** **	**0.008*** **
College housing	(0.000)	(0.001)	(0.001)
Average Age of	-0.003	-0.007	-0.010
freshman	(0.002)	(0.005)	(0.007)
% Minority	-0.001	-0.002	-0.003
(- Asian)	(0.000)	(0.001)	(0.002)
% International	0.002	0.006	0.009
	(0.002)	(0.004)	(0.006)
Urban	0.000	0.000	0.001
	(0.000)	(0.001)	(0.001)
Suburban	-0.000	-0.000	-0.000
	(0.000)	(0.000)	(0.001)
State Unemp,	**0.011*** **	**0.031*** **	**0.044*** **
Rate	(0.004)	(0.011)	(0.015)
NSF Stipend to	**-0.020*** **	**-0.056*** **	**-0.080*** **
Wage Ratio	(0.002)	(0.006)	(0.009)
Observations	11,149		
Institutions	1,035		

Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

Regardless of specification, we find no support for the hypothesis that institutions that have more international students are either more likely to output one or more PhDs or that they have a higher rate of PhD output (either conditional or unconditional). In none of the specifications is the international variable significant. There is, however,

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[60] Panel 1 censored: 31.3%, uncensored: 68.7% (mean rate = 2.04, overall mean rate = 1.40). Panel 2 censored: 32%, uncensored: 68% (mean rate = 1.98, overall mean rate = 1.34). Panel 3 censored: 30%, uncensored: 70% (mean rate = 2.15, overall mean rate = 1.51).

weak evidence that PhD output is negatively related to the percent minority students, although only when the percent of freshman from the top 10% of their high school class is used as the measure of ability.

From an institutional perspective, and regardless of which ability measure is used, several variables play a significant role in PhD output. Here we focus on the marginal effects of institutional variables on unconditional PhD output, using the percent of freshmen taking AP in high school as the ability control. We see that a one percentage point increase in the percent of full time faculty with a PhD leads to a .011

Table 4.5c: Student and Faculty Characteristics (SAT Scores), All Tiers, 1990-2002[61]

	(1)c	(2)c	(3)c
	Panel 3: SAT Scores		
25% SAT Verbal	**0.000*****	**0.001*****	**0.002*****
	(0.000)	(0.000)	(0.000)
75% SAT Verbal	**-0.001*****	**-0.002*****	**-0.003*****
	(0.000)	(0.000)	(0.001)
25% SAT Math	**0.001*****	**0.002*****	**0.003*****
	(0.000)	(0.000)	(0.001)
75% SAT Math	**0.000*****	**0.001*****	**0.002*****
25% SAT Verbal	(0.000)	(0.000)	(0.001)
Top S&E Pubs	**0.449*****	**1.368*****	**1.951*****
per faculty	(0.060)	(0.179)	(0.256)
% FT Faculty	**0.003*****	**0.008*****	**0.012*****
With PhD	(0.000)	(0.001)	(0.001)
% Students in	**0.002*****	**0.005*****	**0.008*****
College housing	(0.000)	(0.001)	(0.001)
Average Age of	-0.001	-0.004	-0.006
freshman	(0.002)	(0.006)	(0.009)
% Minority	-0.000	-0.001	-0.001
(- Asian)	(0.000)	(0.001)	(0.002)
% International	0.001	0.004	0.005
	(0.001)	(0.004)	(0.006)
Urban	-0.000	-0.000	-0.000
	(0.000)	(0.001)	(0.001)
Suburban	**-0.000***	**-0.001***	**-0.002***
	(0.000)	(0.001)	(0.001)
State Unemp,	**0.008****	**0.026****	**0.037****
Rate	(0.004)	(0.013)	(0.018)
NSF Stipend to	**-0.022*****	**-0.066*****	**-0.094*****
Wage Ratio	(0.002)	(0.007)	(0.010)
Observations	9,663		
Institutions	905		

Standard errors in parentheses, *** $p<0.01$, ** $p<0.05$, * $p<0.1$

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[61] Panel 1 censored: 31.3%, uncensored: 68.7% (mean rate = 2.04, overall mean rate = 1.40). Panel 2 censored: 32%, uncensored: 68% (mean rate = 1.98, overall mean rate = 1.34). Panel 3 censored: 30%, uncensored: 70% (mean rate = 2.15, overall mean rate = 1.51).

increase in the rate of production per 1000 students, or an increase of .8 percent above the mean. An increase of one top publication per faculty leads to an increase of 2.054 PhDs per thousand students, an increase in the rate of 107% above the mean.[62] We also see that peer effects matter, even after controlling for various measures of ability: institutions with a ten point increase in the rate of students living on campus, produce PhDs at a .08 higher rate, an increase of 4.3% above the mean. We find no evidence, however, that the average age of the freshman class is significantly related to PhD output.

The unemployment rate of the state economy remains significantly and positively related to the PhD output rate once we have controlled for student and institutional characteristics. As the unemployment rate increases by one percentage point, the PhD output rate increases by .044 per 1000 students (or about 3.14 percent above the mean), looking at the unconditional marginal effect for the AP equation. Intuitively, as mentioned above, this is what we would expect; as unemployment rates rise, the prospect of an advance degree has two benefits. First, it allows one to bridge the rough patch in the economy, if the student expects the economy to turn around after a few years in graduate school. Second, it is a way to gain an advantage in the job market. We have seen evidence of this rush to graduate school in the latest economic downturn.

The second economic indicator is the NSF fellowship to wage ratio variable, which is inversely related to the relative cost of training. Regardless of specification, this marginal effect is now negative and significant, suggesting that as the NSF stipends rise

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[62] Note that this is extremely high, but increasing one top paper per faculty member would be quite an undertaking; the mean for all institutions is .05. Possibly more realistic is to double to current output of top publications. An increase to .10 publications per faculty member (an increase of .05 on average) would lead to an increase of production of .075 PhDs per thousand, or 5.4% more than the mean.

relative to the wage, PhD rates drop. Why might this be? One possibility is that NSF stipends are a proxy for the overall stipend level awarded to S&E PhD doctoral students. If this stipend level is relatively high compared to wages, students may be enticed to remain in graduate school, especially if they expect the job market to be better in later years. This duration effect may offset any positive effect that an increase in relative fellowship values has on attracting more students to graduate school.

The urban variable is never significant. The suburban dummy has a small negative and significant effect at the 10% level in the equations that use SAT scores as the measure of ability, suggesting that suburban campuses produce lower rates of S&E PhDs than do rural campuses. Why might this be? Looking at the summary statistics, there are quite a few high-producing institutions in both urban and suburban settings. Only seven percent of Top Research and 36 percent of Top Liberal Arts institutions are rural. However, 36 percent is the largest share across any school type. It appears to be the case that those institutions in rural settings produce S&E PhDs at a higher rate. Perhaps students in rural communities are more apt to focus on studies, be influenced by peer effects, and less likely to be exposed to “other” types of concentrations (e.g., business) that have been shown to draw students away from science.

Table 4.5 clearly shows that institution and student variables matter in the output of PhDs. But to what extent does controlling for institutional and student variables explain away the tier effects reported in table 4.3? This is explored in Table 4.6, which adds tier to the fully-specified model.[63] In all tables that follow, I present only the unconditional marginal effects, since they are arguably the most relevant. Moreover, in

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[63] 4.6a contains HS rank and AP ability measures; 4.6b contains SAT ability measures.

all cases, the signs and level of significance are the same for the other two types of marginal effects not reported.

Table 4.6: Student and Faculty Characteristics, Controlling for Institution Type, 1990-2002[64]

	(3)a	(3)b	(3)c
Ability Variables:	**HS Rank**	**AP**	**SAT**
Top Research	**1.819*****	**2.173*****	**2.021*****
	(0.265)	(0.284)	(0.290)
Other Research	**0.798*****	**1.065*****	**0.805*****
	(0.161)	(0.170)	(0.179)
Tier 2	**0.162***	**0.158***	0.062
	(0.091)	(0.091)	(0.108)
Top Liberal Arts	**2.490*****	**3.224*****	**2.756*****
	(0.221)	(0.238)	(0.239)
% Freshman top 10% HS	**0.024*****		
	(0.002)		
% Freshman top 10-25% HS	0.004		
	(0.002)		
% Freshman Bottom 50% HS	0.002		
	(0.003)		
% Freshman Taking AP in HS		**0.835*****	
		(0.182)	
25% SAT Verbal			**0.001*****
			(0.000)
75% SAT Verbal			**-0.002*****
			(0.001)
25% SAT Math			**0.002*****
			(0.001)
75% SAT Math			**0.002*****
			(0.001)
Top S&E Pubs per faculty	**0.819*****	**1.198*****	**1.080*****
	(0.276)	(0.306)	(0.299)
% FT Faculty With PhD	**0.007*****	**0.007*****	**0.008*****
	(0.001)	(0.001)	(0.001)
% Students in College housing	**0.006*****	**0.007*****	**0.006*****
	(0.001)	(0.001)	(0.001)
Average Age of freshman	-0.002	-0.008	-0.004
	(0.007)	(0.007)	(0.008)
% Minority (- Asian)	**-0.005****	**-0.003***	-0.002
	(0.002)	(0.002)	(0.002)
% International	-0.001	0.004	0.002
	(0.005)	(0.006)	(0.006)
Urban	-0.001	-0.001	-0.001
	(0.001)	(0.001)	(0.001)
Suburban	-0.001	-0.001	**-0.002****
	(0.001)	(0.001)	(0.001)
State Unemp, Rate	**0.043*****	**0.040*****	**0.036***
	(0.016)	(0.015)	(0.018)
NSF Stipend to Wage Ratio	**-0.082*****	**-0.080*****	**-0.094*****
	(0.009)	(0.009)	(0.010)
Observations	10,594	11,149	9,663
Institutions	1,022	1,035	905

Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

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[64] Percent censored and uncensored are the same for all panels as in Table 4.5.

We see that regardless of ability measure, tier effects persist, although they are somewhat muted, once student and institutional variables are controlled for. To be a bit more specific, the marginal effect of a Top Research institution decreases between 1.6 and 2 students per 1000 enrolled, depending upon the ability measure used. This is a decrease of 128-160% of the mean rate (while this seems very large, the mean rate is low to begin with, so the magnitude change appears to be big). The marginal effect of Top Liberal Arts is cut by about one third. Only for Tier 2 does the effect, which was always minimal and only marginally significant, remain approximately the same. We also see that the introduction of the tier variables into the equations mute the effects of the other variables, although they remain significant at standard levels.

The next set of equations examines within-tier effects, using the same independent variables as in Table 4.5. By doing this, we can explore whether certain factors have more of an impact at one type of institution as opposed to another since these estimations drop the restriction of constraining the marginal effects to be the same across type of institution. From a policy perspective it is particularly valuable to know which variables have an impact and if they have more of an impact in certain types of institutional settings than in others. For these estimations, I use high school rank as the measure of ability. I also test to see if the marginal effects differ significantly between those reported for Top Research and those reported for each of the other tiers by running a fully interactive model.[65] The analysis by institution type yields some interesting results. The following section discusses results by type of institution.

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[65] Significant to the .05 level.

Top Research

For Top Research schools, measured faculty attributes have little effect on the rate of PhD output. This likely reflects the minimal variation in these measures within the Top Research institutions. Most top research universities only hire those with doctoral degrees and top publications per faculty member are relatively invariant within these institutions. In addition, for many academic jobs at top research institutions, publishing in top journals is expected (and sometimes required) in order to gain tenure.

Table 4.7: Student and Faculty Characteristics, 1990-2002[66]

	Top Research	Other Research	Tier 2	Top Liberal Arts	Other Liberal Arts
% Freshman top	**0.052*****	**0.015****	**0.010*****	**0.111*****	**0.021*****
10% HS	(0.018)	(0.006)a	(0.002) a	(0.030)	(0.003) a
% Freshman top	-0.002	0.001	**0.006*****	-0.010	**0.013*****
10-25% HS	(0.018)	(0.006)	(0.002)	(0.037)	(0.003)
% Freshman	**0.038***	0.009	-0.000	-0.011	**0.009*****
Bottom 50% HS	(0.020)	(0.008)	(0.002)	(0.038)	(0.003)
Top S&E Pubs	-0.094	-0.369	**1.264****	1.941	0.481
per faculty	(0.686)	(0.560)	(0.599)	(5.694)	(1.283)
% FT Faculty	0.002	**0.005****	**0.008***** a	-0.003 a	**0.015***** a
With PhD	(0.004)	(0.003)	(0.001)	(0.010)	(0.002)
% Students in	**0.012***	0.005 a	**0.004***** a	**-0.034**** a	**0.006***** a
College housing	(0.007)	(0.003)	(0.001)	(0.016)	(0.001)
Average Age of	0.038	-0.080	-0.005	0.532	0.003
freshman	(0.070)	(0.052)	(0.004)	(0.554)	(0.009)
% Minority	0.022	-0.009	**-0.002***	**-0.054****	-0.001
(- Asian)	(0.016)	(0.006)	(0.001)	(0.026)	(0.002)
% International	**-0.053***	0.004	0.002	-0.011	**-0.014***
	(0.030)	(0.011)	(0.004)	(0.038)	(0.007)
Urban	0.002	-0.003	-0.000	-0.007	-0.001
	(0.008)	(0.002)	(0.001)	(0.007)	(0.001)
Suburban	0.002	-0.003	-0.001	0.000	-0.000
	(0.008)	(0.002)	(0.000)	(0.005)	(0.001)
State Unemploy-	**0.266*****	**0.117***** a	0.011 a	**-0.296**** a	-0.011 a
ment Rate	(0.071)	(0.035)	(0.013)	(0.122)	(0.022)
NSF Stipend to	**-0.189*****	**-0.090*****	**-0.032*****	**-0.230*****	**-0.054*****
Wage Ratio	(0.039)	(0.017)	(0.007)	(0.063)	(0.013)
Observations	761	1187	3900	823	2879
	75	115	370	25	383

Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

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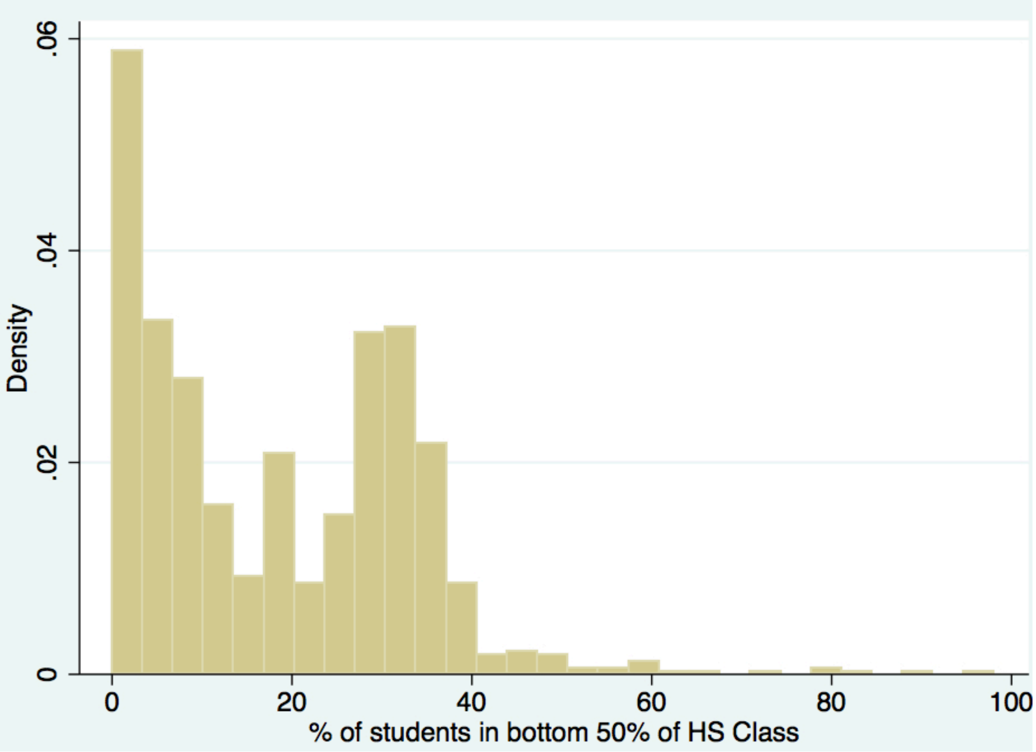
[66] Top Research censored: 0.1%, uncensored: 99.9% (mean rate = 3.93, overall mean rate = 3.93). Other Research censored: 3.1%, uncensored: 96.9% (mean rate = 1.71, overall mean rate = 1.66). Tier 2 censored: 33.8%, uncensored: 67.2% (mean rate = .88, overall mean rate = .59). Top Liberal arts censored: 7.0%, uncensored: 93.0% (mean rate = 5.07, overall mean rate = 4.71). Other Liberal Arts censored: 49.9%, uncensored: 50.1% (mean rate = 1.81, overall mean rate = .91).

There is, however, one curious finding and that is that both top high school students and bottom high school students have a positive relationship with PhD output at top research schools. Figure 4.11 is a histogram of the distribution of these students.

Figure 4.11: Distribution of Students from Bottom Half of HS Class, Top Research Institutions



As can be seen, the distribution is somewhat bi-modal. The marginal effects indicate that for a one point increase in students coming from the bottom half of their high school class, the PhD output rate will rise by .038 PhDs per one thousand, which is an increase of 9 percent over the unconditional mean rate of 3.93 PhDs per thousand students. Why might this be? Perhaps peer effects really are playing a role here; students of lower ability (relative to others in their high school class), when given an opportunity to attend a top research university, can actually increase the institution's PhD output rate more so than students who come from the 50th-75th percentile benchmark.[67]

One peer effect variable matters for Top Research institutions: the percent of students in college housing. This may reflect that many of the universities are very large and have a relatively low percent of students living on campus.[68] Those with higher rates of on-campus lodging are more productive than others; an increase of 10 percentage points of students living on campus results in an increase .12 PhDs per 1000 students, 3 percent above the mean. The percent of international students on a campus actually has a negative effect on the rate of PhD output, meaning that for every one percentage point increase in the population of international students, the rate of PhD output drops by 1.3 percent of the mean. This may reflect the fact that international students at these top schools return to their home countries for graduate school, or they might go on to medical school, business school, or other graduate programs outside of S&E doctoral degrees.

The NSF stipend to wage ratio remains negative and significant, indicating that as NSF stipends rise relative to starting salaries, the rate falls. Again, this may reflect a slowing of the rate: as graduate school pay increases relative to wages, students stay in graduate school longer. It may also reflect the fact that the NSF stipend is relatively stable across time (and always steady across institutions), while the average starting salary changes from year to year. If average S&E PhD salaries rise and fall with BA salaries, S&E grads may be encouraged to enter a PhD program in order to be eligible

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[67] This was chosen as the omitted category so that percentage of top students as well as percentage of bottom students could be analyzed. In other words, the 50-75th percentile group was as close to the 'average' in the reporting of this variable.

[68] Forty-three percent on average, compared with over 60% for liberal arts institutions.

for the higher PhD salaries.[69] Finally, the state unemployment rate is significant with the expected sign. *Other Research Institutions*

We can see that the presence of top students matter at other research institutions, although the effect on S&E PhD output is significantly different (and lower) than at Top Research institutions. Faculty research does not have a significant impact on productivity at these institutions, while the percentage of faculty with a PhD has a very small positive and significant effect. For every one percent increase in faculty with a PhD, the rate increases by .005 per 1000 students, an increase of .3% above the mean unconditional rate. The state unemployment rate matters as well, although the effect is significantly lower than for Top Research universities. The NSF stipend variable remains negative and significant.

Tier 2

Tier 2 institutions have the most variation across the independent variables; there are many more institutions and, unlike the other two tiers, Tier 2 is not spilt into “top” and “all other.” Therefore, it is not surprising that these results mirror those of the overall results from Table 4.6. Top students matter, faculty matter both in terms of their research output and the percent with PhDs, and peer effects matter although the effect is significantly lower than at Top Research institutions. Perhaps the most important finding

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[69] It may also be that the NSF variable is collinear with other variables, causing the once-positive coefficient to switch signs. The correlation matrix for variables used in the estimations is presented in the Appendix (Table A.5). It does not appear that this is the case; the NSF variable has very little correlation with any of the other variables presented in table 4.7.

for Tier 2 is that it is only for this group of institutions that faculty publications are significantly related to PhD output.[70]

Top Liberal Arts

Again, top students matter. Top Liberal Arts institutions average almost half of their students from the top 10 percent of their high school class and it makes a difference. If an institution could increase this by 10 percentage points, it would increase production, on average, by .111 S&E PhDs per 1000 students, or 2.4 percent increase in the mean.

A surprising finding is the negative sign on students in college housing and on the unemployment rate. In both instances the marginal effects are significantly different from those reported for Top Research Institutions. Consider first the marginal effect of the housing variable which implies that the greater the percent of students living on campus, the lower is the rate of PhD output. Top Liberal Arts institutions house almost all of their students (86 percent) on campus, but the result suggests that this is more than optimal for PhD output (or, alternatively, liberal arts institutions with relatively low on-campus housing rates differ from other liberal arts schools in some unknown way positively correlated with S&E PhD output).

Another curious result is the marginal effect for the unemployment variable which is negative and significant. As unemployment drops, PhD rates for Top Liberal Arts institutions rise. Unemployment rates measure the overall state of the labor market, but for many graduates of these top institutions, getting a job is not as much of a challenge

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[70] We cannot, however, reject the hypothesis that the marginal effect of the top publication variable is the same for Tier 2 and for Top Research.

as graduates from, say, Non-Elite Liberal Arts institutions. So, when the general labor market gets better, graduates of elite institutions decide to go to graduate school, perhaps seeing this as a sign that the future return to an advanced degree will prove unusually good. Another explanation could be that the state level unemployment is not the best measure for these types of schools. This is because they appeal to and enroll from a national market, students may not be as inclined to stay nearby after graduation, so the national unemployment rate may be a better indicator of economic conditions facing top liberal arts graduates.

Non-Elite Liberal Arts

Finally, consider the Non-Elite Liberal Arts colleges. Much like Tier 2, because of lots of variation and large numbers of institutions, the results for these institutions also reflect those in Table 4.6, but with a few exceptions. First, all ability levels of students have a positive effect when compared to the omitted category (percent of student from the 50-75th percentile) – a curious result. Essentially, it means institutions produce higher rates of S&E PhDs if they have higher rates of students from either the top quartile or the bottom half of their high school class than those with students coming from the middle of their high school classes. Second, marginal effect of the international student variable is negative, as it was for Top Research.

To summarize, not only does between-tier matter, but within-tier matters as well. From the tables above, we see that the NSF stipend to wage ratio as well as student ability has a significant effect on the rate of PhD output. For non-elite tiers, faculty with terminal degrees have a positive and significant effect on the rate, while the effect is insignificant at top schools (both research and liberal arts).

The next section includes variables to get at selection in the match between students and institutions, a typically unobservable process (i.e., an omitted variable) that I hypothesize can matter a great deal.

Estimation with HERI Variables

As discussed previously, numerous student characteristics are not controlled for in the above estimations. But, as I have noted earlier, variables such as attitude toward graduate school, preferences of the students, etc., are important to consider. The next set of estimations (Tables 4.8 and 4.9) includes individual student data from HERI. Again, only the marginal unconditional effects are presented. The first estimation includes only the variables from HERI. The second estimation combines the institution-level variables with the student-level variables collected by HERI. Because there is no variation in the economic indicator variables,[71] they are omitted. Recall that the HERI variables are mapped to the previous dataset by identifying each institution as one of 21 stratifications. HERI data are summarized by stratification and assumed to be representative of each institution within the stratification. Standard errors clustered on institution type are presented. In both instances, the estimates are restricted to 1996.

Many of the variables are significantly related to PhD output. For example, having more freshmen with a goal of a PhD has a positive and significant effect on PhD output, while having a greater number of seniors with the goal of a PhD, holding constant freshman PhD goals, has no significant effect on production. Perhaps this speaks to the selection issue very strongly: those who come to college with intentions for graduate school (a doctorate, in particular), are much more likely to attain said

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[71] The variation is year to year, and not by institution or by state.

degree than those who claim to want a PhD upon graduation. Consider a 10 percent Increase in the percent of students with plans for a PhD upon entry to undergrad. This results in an increase of PhDs of 2.21 per 1000 students, an increase over the unconditional mean of 168 percent. Compare that to an increase of the same percent wanting to pursue a PhD upon graduation; this leads to a drop – albeit insignificant – in the rate of PhD output.

Table 4.8: HERI Variables, 1996[72]

	HERI
PhD planned: College Entry	**0.221*****
	(0.031)
PhD planned: BA Graduation	-0.026
	(0.045)
Chose BA for ability to prepare students for grad school	**-0.051*****
	(0.015)
Chose to attend college to prepare for graduate school	**0.018*****
	(0.006)
Faculty freq, encouraged grad school	**0.048*****
	(0.016)
Frequently been a guest in a professor's home	**0.085*****
	(0.018)
Mother has PhD/MD/JD	0.009
	(0.009)
Father has PhD/MD/JD	**0.056*****
	(0.014)
Frequent opportunity to work on research project	-0.031
	(0.022)
Frequent opportunity to publish	**-0.065*****
	(0.023)
Worked on an independent research project	**-0.104*****
	(0.018)
Observations	1272

Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

Choosing an undergraduate program for its ability to prepare one for graduate school has a negative and significant marginal effect, while choosing to attend college to prepare for graduate school is positive and significant. This may reflect the selection issue as well; schools that enroll those who see undergraduate school as a stepping

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[72] Censored: 33.6%, uncensored: 66.4% (mean rate = 1.98, overall mean rate = 1.31).

stone to graduate school are more likely to have a higher rate of output than those enrolling students who expect to get into grad programs based (partially or completely) on the institution's reputation for sending students to graduate school.

Faculty exposure variables are as expected; institutions where faculty are more supportive of students (being a guest in a professor's home, encouragement to apply to graduate school) have significantly higher PhD rates of production. Exposure to frequent research projects is not significant, although working independently on research projects has a negative and significant relationship with the PhD output rate. As we saw above, top publications have a positive impact on the rate, so how can these results be reconciled? Perhaps it is an indirect result of the publications (e.g., high-tech labs, great resources, etc.) that has a positive effect, while direct exposure to research through a professor does little to affect the decision to continue to graduate school.

Table 4.9 adds in variables to measure the impact of ability, peer effects, faculty research and student demographics.[73] Clearly, from the HERI summary statistics (presented above) for these variables, we know that different institution types offer different exposures to research and faculty. After adding in these variables, only two of the HERI variables remain significant: having been a guest in a professor's home and planning for a PhD upon college entry.

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[73] Tier indicator variables are not included because they correspond completely with the 21 institution stratifications used in assigning HERI variables to institutions.

Table 4.9: HERI and College Board Variables, 1996[74]

	HERI +
% Freshman top	**0.053*****
10% HS	(0.007)
% Freshman top	0.008
10-25% HS	(0.007)
% Freshman	0.006
Bottom 50% HS	(0.009)
Top S&E Pubs	**1.273*****
Per faculty	(0.451)
% FT Faculty	**0.030*****
w/PhD	(0.005)
% Students in	**0.006***
College housing	(0.003)
Average Age of	-0.012
Freshman	(0.021)
% Minority Students	-0.003
(-Asian)	(0.006)
% International	-0.002
	(0.018)
Mother or Father w/	0.007
PhD/MD/JD	(0.009)
Exposure to	-0.030
research index	(0.026)
PhD planned:	**0.079****
College Entry	(0.040)
PhD planned:	0.034
BA Graduation	(0.045)
Chose BA for ability to prepare	-0.015
students for grad school	(0.015)
Chose to attend college to	0.001
prepare for graduate school	(0.005)
Faculty freq, encouraged	0.019
grad school	(0.017)
Frequently been a guest	**0.046****
in a professor's home	(0.018)
Observations	780

Standard errors in parentheses, *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Estimations by Field

The College Board variables remain significant and have the predicted sign. For every ten percentage point increase in top HS students, the production rate increases .53 PhDs per 1000 students, an overall increase of almost 35 percent above the mean.

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[74] Urban and Suburban are included, but omitted from results as neither was significant. Censored: 33.6%, uncensored: 66.4% (mean rate = 2.29, overall mean rate = 1.52).

Top publications also have a large effect on the PhD output rate, even after controlling for exposures to research. This suggests there are ways a school can increase the rate of output, other than through direct research exposure. There is no support for the hypothesis that underrepresented minorities are less likely to get a PhD, other things being equal. Nor is there evidence of a relationship between international student population enrolled and PhD output.

The road to a PhD in science or engineering is not necessarily the same for any two given fields. In order to explore the possibility that PhD output differs by field of study, I present results for five fields: biological sciences, computer science and mathematics, physical sciences (including physics, chemistry and geological sciences), engineering and economics. Table 4.12 gives the unconditional mean rates by field and institution type:

The patterns seen for total S&E appear to follow here, with the exception of engineering. In other words, Top Liberal Arts and Top Research lead the other institutions in the production of every field, save engineering. In this field, research institutions dominate, most likely because smaller schools often do not offer engineering as a major. It is also interesting to note that Top Liberal Arts institutions dominate in the fields of biology, physical science, and economics, mirroring overall patterns. The chart also makes it clear that degrees in biology, physical science and engineering are pursued at a much higher rate than degrees in computer science, mathematics and economics.

Figure 4.12: Mean PhD Rate, by Field and Tier

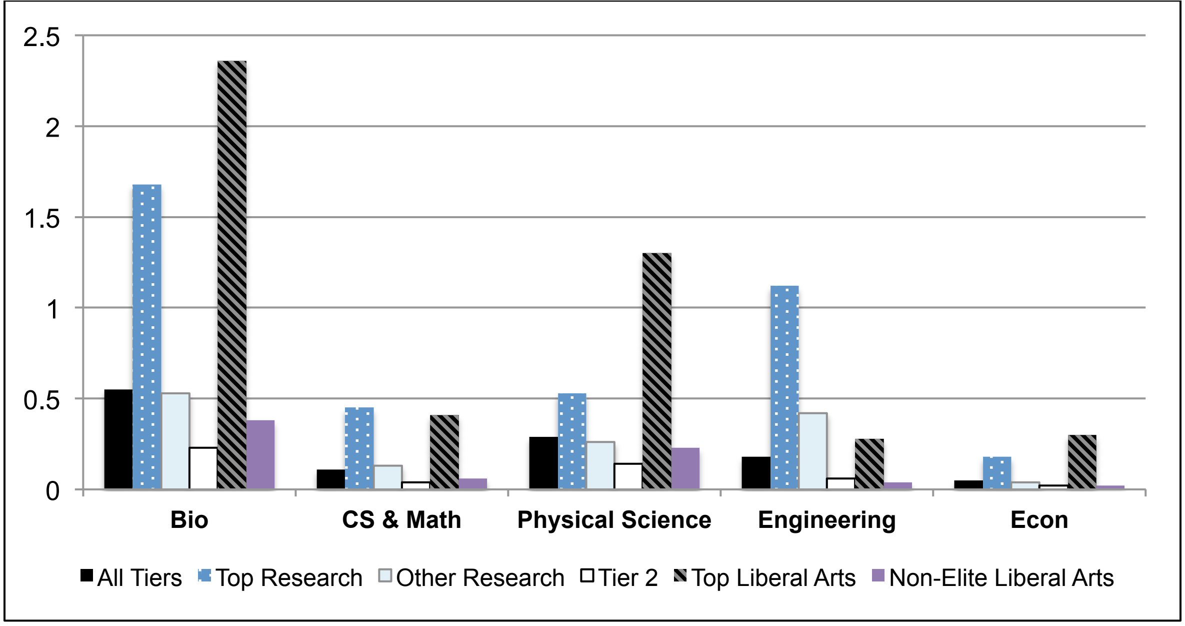

Table 4.10 presents the model using the full data panel (without the HERI variables) for four of the fields listed in Figure 4.12.[75] Engineering had to be dropped due to the small number of observations. Institution type matters here, as it does in overall S&E PhD output. Each tier variable is positive and significant compared to the omitted tier (Non-Elite Liberal Arts), and relative magnitudes reflect those shown in Figure 4.12. The percent of underrepresented minority students has a negative impact on the rate of physical science and economics PhDs, but no significant relationship for the fields of biological sciences or computer science and math. A number of independent variables are significant across all fields. The high school ability measures (all of them) are significant across all fields and we again find the curious result that PhD output is

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[75] Not enough observations/variation due to so many institutions (particularly liberal arts) not offering engineering as an undergraduate major.

Table 4.10: Full Model by Field, Combined Effect, 1990-2002[76]

DV: Rate of PhD Output in Field	Bio	CS & Math	Physical Science	Engineering	Econ
Top Research	**0.556*****	**0.215*****	**0.125****		**0.106*****
	(0.097)	(0.036)	(0.055)		(0.021)
Other Research	**0.300*****	**0.134*****	**0.132*****		**0.048*****
	(0.063)	(0.022)	(0.039)		(0.010)
Tier 2	**0.093*****	**0.036*****	**0.050****		**0.015*****
	(0.035)	(0.009)	(0.022)		(0.004)
Top Liberal Arts	**1.012*****	**0.119*****	**0.482*****		**0.088*****
	(0.094)	(0.024)	(0.062)		(0.016)
% Freshman top	**0.014*****	**0.003*****	**0.007*****		**0.001*****
10% HS	(0.001)	(0.000)	(0.001)		(0.000)
% Freshman top	**0.004*****	**0.001*****	**0.004*****		**0.000*****
10-25% HS	(0.001)	(0.000)	(0.001)		(0.000)
% Freshman	**0.003****	**0.001*****	**0.002*****		**0.000***
Bottom 50% HS	(0.001)	(0.000)	(0.001)		(0.000)
Top Field Pubs	**2.340*****	**3.776*****	0.467		**0.898*****
Per faculty	(0.750)	(0.826)	(0.482)		(0.250)
% FT Faculty	**0.006*****	**0.001*****	**0.004*****		**0.000*****
w/PhD	(0.001)	(0.000)	(0.000)		(0.000)
% Students in	**0.003*****	**0.000****	**0.001****		**0.000***
College housing	(0.001)	(0.000)	(0.000)		(0.000)
Average Age of	-0.004	0.000	0.001		-0.001
Freshman	(0.003)	(0.001)	(0.002)		(0.000)
% Minority Students	-0.001	0.000	**-0.002*****		**-0.000****
(minus Asian)	(0.001)	(0.000)	(0.001)		(0.000)
% International	-0.005	-0.001	-0.002		0.000
	(0.003)	(0.001)	(0.002)		(0.000)
Urban	-0.000	0.000	-0.000		0.000
	(0.000)	(0.000)	(0.000)		(0.000)
Suburban	0.000	-0.000	**-0.000***		-0.000
	(0.000)	(0.000)	(0.000)		(0.000)
State Unemployment	0.000	0.001	-0.008		-0.000
Rate	(0.009)	(0.002)	(0.006)		(0.001)
NSF Stipend to Wage	**-0.040*****	**-0.005*****	**-0.017*****		-0.001
Ratio	(0.006)	(0.002)	(0.004)		(0.001)
Observations (Institutions)	10,594 (1,022)				

Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

positively and significantly related to the percent coming form the bottom of their high school class. Faculty measures are significant in each field with the exception of top

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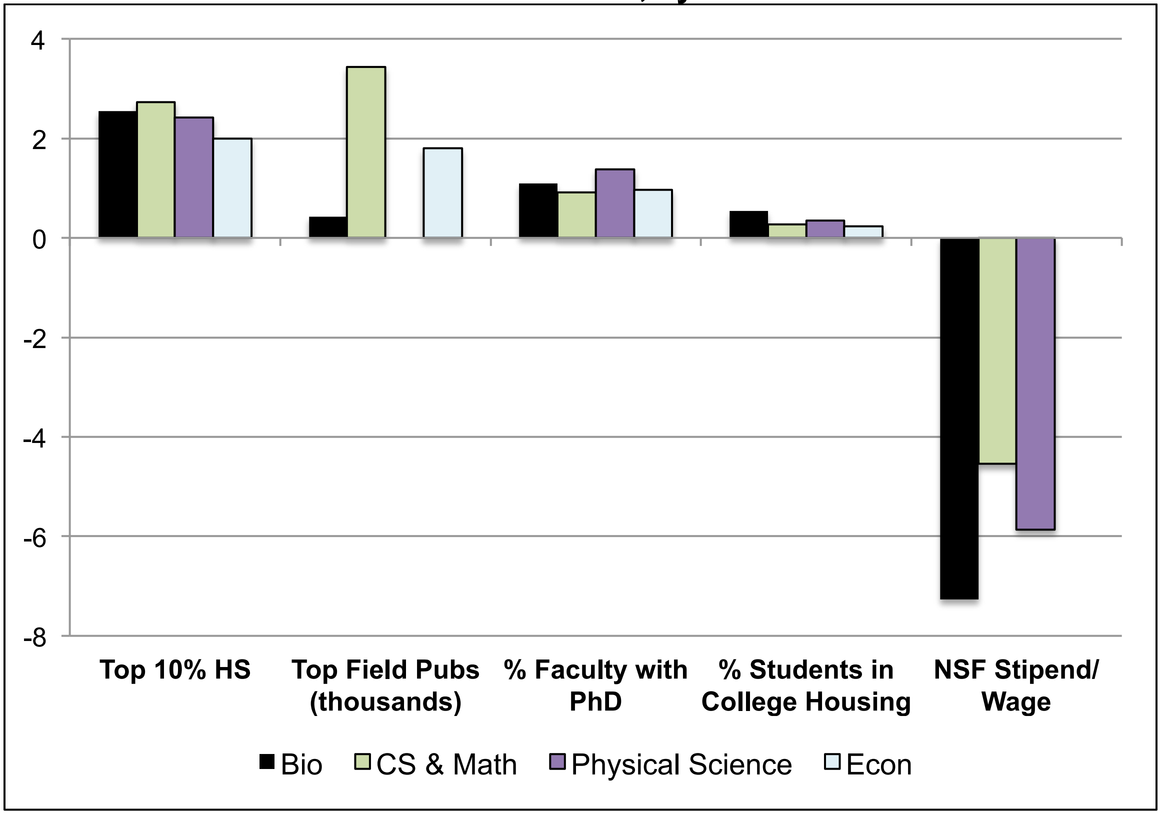
[76] Bio censored: 50.3%, uncensored: 49.7% (mean rate = 1.11, mean rate (all) = .55). CSM censored: 78.2%, uncensored: 21.8% (mean rate = .51, mean rate (all) = .11). Physics censored: 72.7%, uncensored: 37.3% (mean rate = .77, mean rate (all) = .29). Engineering censored: 77.7%, uncensored: 22.3% (mean rate = .785, mean rate (all) = .18). Economics censored: 88.3%, uncensored: 11.7% (mean rate = .43, mean rate (all) = .05).

publications in the physical sciences. Peer effects are significant for each field. The NSF stipend variable is negative and significant for all fields save economics. The state unemployment rate is never significant.

To better illustrate a comparison between these field marginal effects, estimated increases or decreases to the mean rates are presented in Figure 4.13. Each bar represents a one unit increase in the independent variable, and its estimated impact on the mean rate.[77] While we cannot say by looking at this figure which marginal effects are significantly "more" or "less" important, we can see clear differences between fields.

Figure 4.13: Estimated Marginal Effects, Percent Increase/Decrease on the Mean Rate, by Field



Consider the effect of top publications in the field. Its impact on computer science and math productivity is much higher relative to economics and biology (the marginal

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[77] Only marginal effects that are significant are included in the figure.

effect for physics is not significant). Peer effects (students in college housing) appear to have the greatest impact on the rate of PhD output in biology, as does the NSF to wage ratio.[78]

Finally, I add the HERI variables to measure the effect of selection and run the estimates for 1996. Table 4.11 presents the HERI variables for each of the fields listed above. Table 4.12 adds the institution level variables. In Table 4.11, we see that planning a PhD upon college entry has a significant impact on the rate in all fields except physical science, while planning to get a PhD at the time one graduates only has a significant effect in engineering. Figure 4.7 shows that plans for getting a PhD more than doubles, regardless of tier, from entry in college to graduation. Perhaps only those who really want a PhD at the start of their college career are well prepared for a PhD and can stick with it, thus having an effect on the production rate. The same interesting result is present here as above for all of S&E: for three of the five fields, choosing the institution for *its ability to prepare students* for graduate school actually has a negative partial correlation with the rate, while students who chose to attend college in general in order *to prepare themselves* for graduate school has a positive effect on the rate in three out of five fields. Exposure to research, in almost all forms and for almost all fields, has a negative effect on the rate. The exception is Physics and being given a frequent opportunity to publish.

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[78] This may be explained by the difference in time to degree by field. Biological sciences had an average time to degree of 9 years in the middle-1990s, while the physical sciences (including math and computer science) had an average time to degree of around 8.4 years. (Hoffer and Welch 2006) In other words, those in the biological sciences are more prone to increasing time in a PhD program when the market is relatively bad.

Table 4.11: HERI Variables by Field, Combined Effect, 1996 Only

DV: Rate of PhD Output in Field	**Bio**	**CS & Math**	**Physical Science**	**Engineering**	**Econ**
Mean Rate					
PhD planned:	**0.095*****	**0.019*****	0.008	**0.028*****	**0.006*****
College Entry	(0.015)	(0.004)	(0.009)	(0.005)	(0.002)
PhD planned:	-0.014	0.009	0.020	**0.016***	-0.001
BA Graduation	(0.023)	(0.006)	(0.014)	(0.009)	(0.003)
Chose BA for ability to prepare	**-0.021*****	**-0.006*****	**0.008***	**-0.010*****	-0.001
students for grad school	(0.008)	(0.002)	(0.005)	(0.003)	(0.001)
Chose to attend college to	**0.009*****	0.000	**0.004****	-0.000	**0.001****
prepare for graduate school	(0.003)	(0.001)	(0.002)	(0.001)	(0.000)
Faculty freq, encouraged	**0.017****	0.001	0.003	0.003	0.002
grad school	(0.008)	(0.002)	(0.005)	(0.003)	(0.001)
Frequently been a guest	**0.042*****	0.003	**0.027*****	**-0.012*****	0.000
in a professor's home	(0.009)	(0.002)	(0.005)	(0.003)	(0.001)
Mother has	**0.008***	0.002	**0.009*****	-0.001	-0.000
PhD/MD/JD	(0.005)	(0.001)	(0.003)	(0.002)	(0.001)
Father has	**0.029*****	0.003	0.004	**0.006****	**0.004*****
PhD/MD/JD	(0.007)	(0.002)	(0.005)	(0.003)	(0.001)
Frequent opportunity to	-0.014	-0.004	0.002	-0.007	**-0.006*****
work on research project	(0.011)	(0.003)	(0.007)	(0.004)	(0.002)
Frequent opportunity	**-0.022***	**-0.006****	**0.013***	**-0.011*****	-0.001
to publish	(0.011)	(0.003)	(0.007)	(0.004)	(0.002)
Worked on an independent	**-0.038*****	**-0.005****	**-0.031*****	**-0.009*****	-0.002
research project	(0.009)	(0.002)	(0.006)	(0.003)	(0.002)
Observations			1,272		

Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

While the preceding evidence gives us a snapshot of the issue of selection, it does not include other factors thought to be significant. Table 4.12 adds in student, faculty, and institution characteristics in order to explore the combined effects while hopefully accounting for selection, at least selection on the measurable variables. It uses the research index variable to measure different types of exposure to research. Once the other variables are included, the HERI variables – for the most part – become insignificant. There are a few exceptions. First, the index variable measuring exposure to research is actually negative for computer science and math, and engineering. This indicates that as students in these disciplines are assigned independent research or offered opportunities to publish, or work with a professor on research, the number of students eventually getting a PhD is estimated to decrease.

Table 4.12: HERI & College Board Variables by Field, Combined Effect,1996 Only

DV: Rate of PhD Output in Field	Bio	CS & Math	Physical Science	Engineer-ing	Econ
Mean Rate					
% Freshman top	0.021***	0.003***	0.013***	0.002***	0.002***
10% HS	(0.003)	(0.001)	(0.002)	(0.001)	(0.000)
% Freshman top	0.006	0.002*	0.005*	0.002*	0.000
10-25% HS	(0.004)	(0.001)	(0.003)	(0.001)	(0.001)
% Freshman	0.003	0.002	0.005	-0.000	0.000
Bottom 50% HS	(0.005)	(0.001)	(0.003)	(0.001)	(0.001)
Top S&E Pubs	4.230**	7.683***	-0.104	3.260***	1.071
Per faculty	(1.714)	(2.583)	(1.252)	(1.040)	(0.728)
% FT Faculty	0.013***	0.001***	0.007***	0.002***	0.001**
w/PhD	(0.002)	(0.001)	(0.002)	(0.001)	(0.000)
% Students in	0.004**	0.000	-0.000	0.000	0.000
College housing	(0.002)	(0.000)	(0.001)	(0.000)	(0.000)
Average Age of	0.000	-0.004	0.000	-0.005	-0.000
Freshman	(0.011)	(0.003)	(0.008)	(0.003)	(0.001)
% Minority Students	-0.001	-0.000	-0.004*	-0.002**	-0.001
(-Asian)	(0.003)	(0.001)	(0.002)	(0.001)	(0.000)
% International	-0.007	0.001	-0.001	0.003	0.001
	(0.010)	(0.002)	(0.007)	(0.002)	(0.001)
Urban	-0.000	0.000	-0.000	0.000	0.000**
	(0.001)	(0.000)	(0.001)	(0.000)	(0.000)
Suburban	0.000	-0.000	0.000	-0.000	0.000
	(0.001)	(0.000)	(0.001)	(0.000)	(0.000)
Mother or Father w/	0.002	-0.000	-0.003	0.001	-0.000
PhD/MD/JD	(0.004)	(0.001)	(0.003)	(0.001)	(0.000)
Exposure to	0.012	-0.006**	0.000	-0.008***	-0.002
research index	(0.013)	(0.003)	(0.009)	(0.003)	(0.002)
PhD planned:	0.026	0.007*	-0.006	0.008*	0.001
College Entry	(0.020)	(0.004)	(0.014)	(0.004)	(0.002)
PhD planned:	0.023	0.008	0.005	0.007	0.007***
BA Graduation	(0.023)	(0.005)	(0.016)	(0.006)	(0.003)
Chose BA for ability to prepare	-0.002	-0.003*	0.003	-0.001	-0.002**
students for grad school	(0.008)	(0.002)	(0.005)	(0.002)	(0.001)
Chose to attend college to	-0.001	-0.000	0.001	-0.009***	0.000
prepare for graduate school	(0.003)	(0.001)	(0.002)	(0.001)	(0.000)
Faculty freq, encouraged	-0.008	-0.002	-0.008	0.002	-0.003***
grad school	(0.009)	(0.002)	(0.006)	(0.002)	(0.001)
Frequently been a guest	0.021**	-0.001	0.016**	-0.009***	-0.000
in a professor's home	(0.009)	(0.002)	(0.007)	(0.003)	(0.001)
Observations			780		

Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

How can this be reconciled with the results above (e.g., higher publications rates of faculty lead to higher rates of PhDs)? Perhaps the faculty who produce top journal articles also possess certain other qualities which lead to higher rates of PhD attainment, such as a passion for research. Once the propensity to publish in top journals is accounted for, spending time in undergraduate research rather than in other academic activities might decrease the eventual PhD output rate. It is also possible the type of work undergraduates do in a lab is not research experience-enhancing, but to the student feels more like a typical minimum wage job.

Planning early in one's college career is slightly significant in the computer science and math and engineering PhD rates, but in no other fields. Interestingly, planning to get a PhD at the time of graduation now has a positive and significant marginal effect in the field of economics, but not in physics, as in Table 4.11. This probably reflects the fact that few students begin college expecting to be economics majors, but many bright students subsequently major in economics following exposure to the subject.

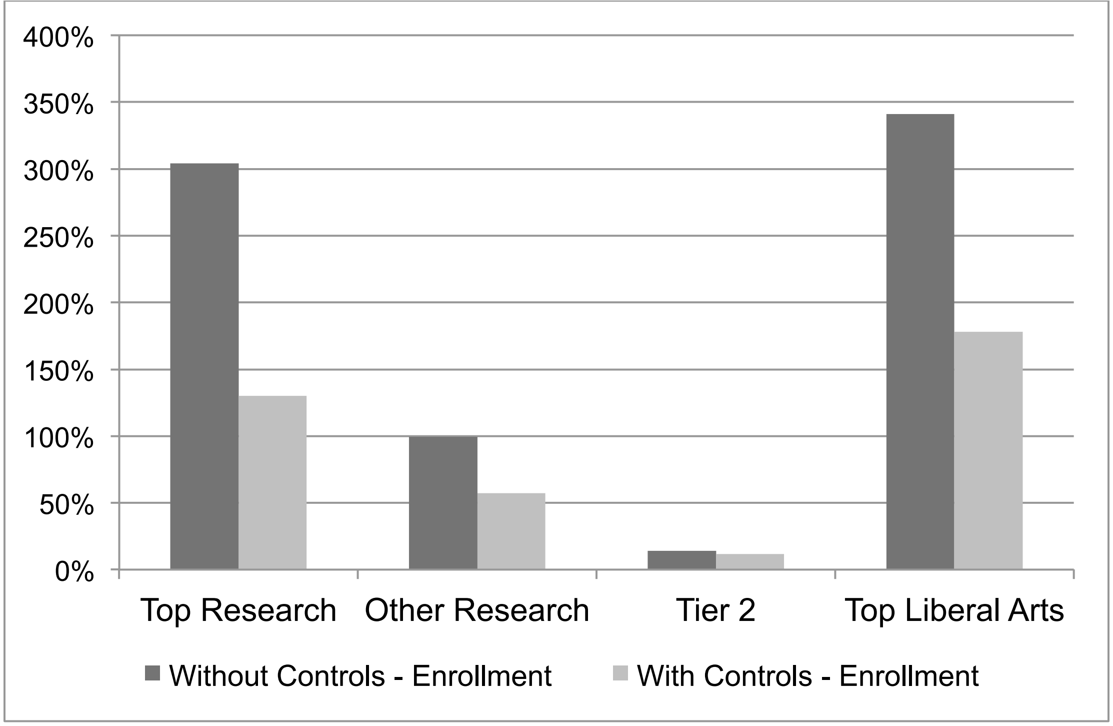
Conclusion

This chapter estimated a reduced form model of PhD output that draws on the literature reviewed in Chapter II, concerning how institutions can affect PhD output, and that of Chapter III, which examines factors influencing an individual's decision to get a PhD. While we already knew from published aggregate data that PhD output varies by institutional tier, we did not know either the extent to which productivity can be explained by specific characteristics of institutions and their students, or the degree to which tier effects persist after controlling for such characteristics and for other factors related to opportunities for study and the state of the labor market. We also did not know the degree to which institutional, individual, and economic characteristics affect PhD output within individual tiers. While it appears reasonable to hypothesize that some portion of the large tier effects are related to selection (the matching of students and schools), prior research has neither addressed this issue nor the question of how PhD output varies by field. This chapter explores these issues.

What does the multivariate Tobit regression analysis of PhD output in S&E provide that simple mean rates do not? I begin with simple relationships (roughly akin to descriptive mean rates of PhD completion by tier groups) and then carefully build up to a comprehensive model. I first begin by augmenting the tier variables with economic variables. From this, we see there is a clear-cut effect of state unemployment rates and the average graduate school stipend (relative to the wage) on PhD output. Tier effects persist, as expected and as discussed in the chapter. Next adding student characteristics (as a proxy for peer effects and ability) and faculty/institutional characteristics, we see that many of these matter, some a considerable amount. Ability of students and faculty publications (as well as percent with a PhD) play a large role in explaining variation in PhD output rates across institutions.

Moreover, we learned that even after controlling for student and institutional characteristics that vary enormously across tiers, the tier indicators still have sizable and significant effects on PhD output. In Figure 4.14, I show the impact of the tier coefficients (evaluated at the mean of the base category, Non-Elite Liberal Arts) without any other variables included (with the exception of time) compared to the impact of tier coefficients after including institution and economic variables.

Figure 4.14: Impact of Tiers, With and Without Other Explanatory Variables



How do we interpret this graph? Despite detailed controls, there remain unobservable and/or un-measureable characteristics affecting PhD output that differ systematically by tier, although the tier effects are decreased by more than half. As mentioned above, previous research has not addressed the issue of selective matching between students and institutions. Accounting for selection in a comprehensive and compelling manner is very difficult and was not fully possible in this research. This paper attempts to control for selection by using a variety of institutional-level characteristics that, a priori, are though to impact PhD output. It is important to note that selection and ability cannot be controlled for fully, thus the results should be interpreted with caution. But progress was made on this score using student specific information from the HERI data. Based on the analysis in this chapter, I conclude that much of what are typically regarded as tier effects on PhD output are in fact due to the selective matching between students and their undergraduate institutions.[79]

More concretely, by adding measures for selective matching and proxies for individual opportunities, we see that ability, faculty characteristics and success, and peer effects maintain significant, positive effects on rates of PhD output. Finally, rates vary not only by institution type, but also by field. Results by field are largely similar to those found for all S&E, but are not consistent across all tiers. Clearly, there exists substantial heterogeneity in the production of S&E PhDs across fields and undergraduate institutions.

What does this mean for undergraduate (and graduate) institutions? For students who desire to obtain a PhD? For policy makers encouraging higher rates of S&E graduates? The final chapter of this dissertation discusses policy implications and strategies aimed at increasing PhD output rates, and what those increases could mean for stakeholders.

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[79] While the HERI data are valuable to this study, there are two ways the analysis might be improved. First, year over year data for The Freshman and The Senior Surveys could be incorporated. Seeing time trends would allow for a more accurate picture to be painted about the relationship between the HERI variables and certain types of institutions. Second, linking each institution to its own survey results, rather than to results averaged within tiers, would be extremely valuable. Such analysis would provide substantially more information and allow a fuller picture to be painted: student characteristics, faculty characteristics, institution level variables, and survey responses over time within individual institutions. Following such analysis, the residual differences across tiers should provide more reliable estimates of the true effects of institutional type on the PhD output process.

Chapter V

CONCLUSION AND POLICY IMPLICATIONS

This dissertation examines the determinants of PhD output at the undergraduate level. Chapter I, the introduction, explains why output of PhDs is important for economic growth and innovation, as well as providing a historical overview of the topic. Chapter II focuses on the theory underlying the objectives and production functions of higher education institutions, and the related objective and output of doctoral students in science and engineering. Chapter III continues the theoretical discussion by looking at the individual's decision to pursue a doctoral degree. Finally, Chapter IV combines the theory with data, and employs a reduced form model to estimate determinants of and relationships between institution, student and economic factors that relate to higher levels of PhD output. This final chapter summarizes policy implications for institutions and government regarding what can be done to increase PhD output in science and engineering. Following discussion of the implications, I look at overarching conclusions and also the role selection plays in the results.

Implications for Institutions

What can an institution do to increase PhD output if it desires to do so? As found in Chapter IV, institutional characteristics have a considerable impact on PhD rates.

Broadly speaking, institutions can increase the quality of students attending, promote peer effects and employ faculty whose characteristics promote the output of PhDs.

Student ability variables impact the rate through two channels. The first is through that of selection; higher-ability students are more likely to pursue a graduate degree and be successful in graduate school. Even when controlling for selection effects, the measured ability of students at an institution has a positive impact on PhD productivity. I argue this reflects both peer effects and innate ability. In other words, institutions with higher ability students not only graduate students who are more likely to pursue a PhD and succeed in graduate school, but the presence of high ability students also has a positive effect on the graduate school plans of other students. Schools can capitalize on this by recruiting and incentivizing high-ability students. High SAT math scores and high relative high school rank are two telling ability factors related to high S&E PhD output. In order for these ability peer effects to be maximized, other institutional characteristics can be altered. For example, the number of students living on campus generally has a positive impact on the rate of PhD productivity, most likely because it allows for greater peer-to-peer influence and exchange of ideas.

In addition to peer effects, faculty characteristics matter as well. Students pursue S&E PhDs at a higher rate when their undergraduate institution has high levels of faculty with a PhD in their field. Similarly, PhD productivity is related to high rates of top journal publications on the part of the faculty. The relationship, however, is likely indirect, reflecting, for example, strong networks of highly productive faculty and the opportunities such networks provide students. Changing the productivity of faculty may, moreover, be more difficult than increasing the number of students living on campus or increasing admission standards. At a minimum it requires the institution to look at the larger picture and focus not only on faculty, but institutional characteristics that will enhance research, (lab facilities, for example). While increasing top journal publications is likely a goal of most institutions, given that publishing research is arguably not associated with a direct effect on student graduate school outcomes, institutions may decide to focus on other variables that have a more direct relationship to increasing PhD productivity.

Implications for Government

As discussed in Chapter I, there are reasons to encourage the production of PhDs in S&E at a national level. The rationale: research leads to scientific discoveries and the development of new technologies, which in turn, lead to economic growth and higher standards of living. What then can government do to incentivize institutions and/or students to pursue graduate degrees in science and engineering?

Consider the two economic indicator variables used in the analysis from Chapter IV: the state unemployment rate and NSF stipends. We see that as unemployment rates rise, graduation rates for PhDs also rise. Clearly, raising unemployment in order to encourage PhD production is not a policy governments should pursue. However, the counter cyclical nature of PhD productivity does suggest that during periods of high unemployment the government could further enhance PhD productivity by increasing the number and level of fellowships for graduate study.

Consider the second variable, which is the NSF stipend relative to the average wage for college graduates. The marginal effect sign of this variable was negative, indicating that as the NSF stipend rises, PhD productivity decreases[80]. It is assumed this is due to one of two things. First, it could be a lengthening of time to graduation. In other words, absolute degrees may not be affected as much as time to degree. If this is the case, a time limit on the stipend might be the solution: a higher stipend might lead students to choose graduate school, but if that stipend is limited to five years, for example, students might be incentivized to complete the degree sooner.[81] Second, it may also reflect the fact that the average starting salary (the denominator in the variable) changes year to year, while the NSF stipend is relatively stable across time. This suggests that the decision to enter a PhD program might be encouraged by government policies that promote salary growth in S&E occupations relative to other occupations. Finally, it should be noted that our analysis controls for the relative value of the NSF stipend, not the number of stipends. Work by Freeman et al. found PhD attendance to be highly responsive to the number of fellowships available. Thus, increasing the number of fellowships is another possible action that the government could undertake to increase PhD productivity.

Can the government impact any of the other significant variables? It is clear from the above discussion that students are influenced by a number of institution-level characteristics, which the government could provide incentives for enhancing. For example, peer effects are important, so relatively more funding could be offered to

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[80] Note that it is not only the NSF stipend rates being consider, but it is assumed that other graduate level stipends rise with the NSF award. In other words, NSF stipend levels are simply a proxy for the award levels of graduate departments.

[81] Many graduate schools limit the length of funding allowed to their students, as does NSF (which awards 3 years of funding). However, even with limited years of unconditional funding, many graduate students end up in a position after four or five years to earn research assistantships, teaching assistantships, or other opportunities that provide funding. In short, once a student has opportunities to earn income – especially livable income – it is in turn reflected in the time to degree.

schools to augment peer effects (high rates of students living on campus, programs promoting student interactions, etc.).

There is also an opportunity to influence students before they reach college. The HERI data suggest that schools which enroll students planning on a PhD in S&E upon entering college are significantly more likely to have a higher PhD output rate. The trend to teach to standardized tests has made it more difficult for research-based coursework to exist in secondary schools. Incentivizing and creating opportunities for students to practice research and become engaged early on could result in increased desire for science education beyond college.

Concluding Remarks

This dissertation provides an overview of what drives PhD output in the United States. The student, the institution, and the economy all play a role in explaining how productivity levels change over time. The significance of faculty, student and other institutional characteristics indicates that many of these factors impact PhD output. But a main result of the empirical analysis in Chapter IV is that even after controlling for these characteristics tier matters, suggesting that selection plays a large role in explaining differentials across tiers.

Controlling for selection thus appears to be key in understanding how PhD productivity varies across institutions and tiers. This dissertation attempts to control for selection through the HERI Freshman and Senior Survey results. However, the limited amount of institution information that is available and the fact that what is available is only available for one year means that selection as it relates to tiers cannot be analyzed. Had schools been identified, testing tier level impacts and changes over time could have been possible, and the selection issue could have been further addressed.

In addition to the gains to be made with regard to selection, there are a number of other issues to explore further, such as the impact of primary and secondary education on PhD output, the graduate school's role in production (i.e., what happens once a student is accepted into a graduate program), and how international issues play a role in determining PhD production.[82] Another area that invites further investigation is substitution of other majors for S&E – such as business – and the impact of substitution on production.

What has been shown in the previous chapters is that the usual suspects do matter in PhD productivity: student ability, selection, faculty influence, economic conditions, and institution type. Given this, what this dissertation adds is the extent to which the above variables are related to PhD output, and how each differs based on the type of institution and field in which the degrees are awarded.

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[82] There is a significant literature on international PhD students and their relationship to the supply of domestic PhDs.

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APPENDIX

This Appendix explores in further depth the difference in using graduates vs. enrolled students as the base when measuring PhD output. First, consider summary statistics for each. Table 4.2a is shown here along with Table A.1 (using graduates as the denominator) for comparison. Graduation rates by tier are presented in Table A.2.

Table 4.2a PhDs per 1000 enrolled students: Zero and Non-Zero Observations by Tier

	All	Top Research	Other Research	Tier 2	Top LA	Non-Elite LA
Rate of all observations	1.25	4.32	1.51	0.52	4.86	0.78
Observations with rate = 0	5,949	8	103	2,233	68	3,537
Percent observations with rate=0	35.9%	0.7%	5.78%	35.1%	6.6%	56.4%
Rate of observations with rate>0	1.95	4.35	1.60	.80	5.20	1.79

Table A.1 PhDs per 1000 graduates: Zero and Non-Zero Observations by Tier

	All	Top Research	Other Research	Tier 2	Top LA	Non-Elite LA
Rate of all observations	6.39	20.52	7.78	3.05	21.29	4.41
Observations with rate = 0	5,949	8	103	2,233	68	3,537
Percent observations with rate=0	35.9%	0.7%	5.78%	35.1%	6.6%	56.4%
Rate of observations with rate>0	9.97	20.65	8.26	4.70	18.40	10.12

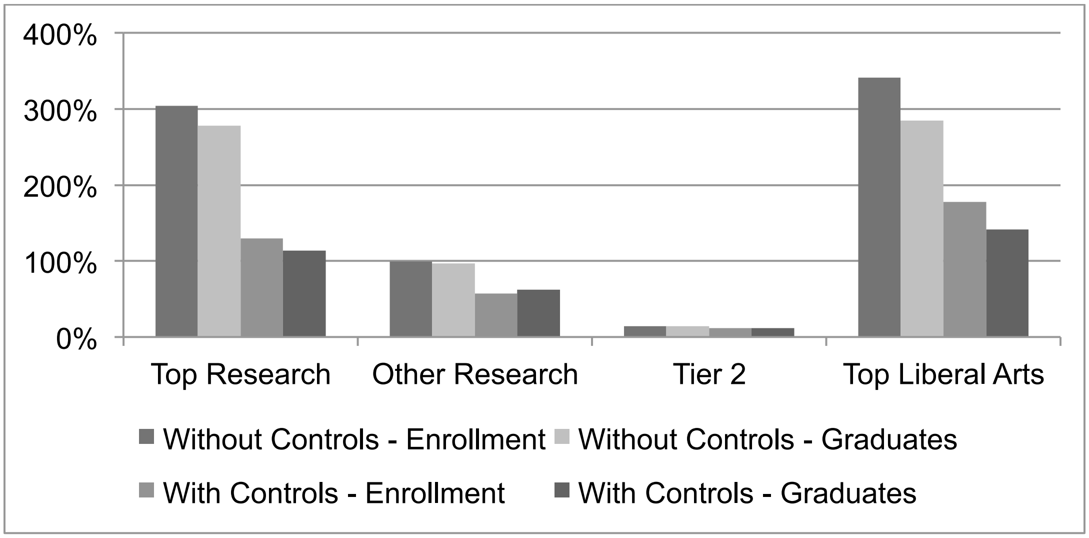
Table A.2 Six-Year Graduation Rates by Tier

	All	Top Research	Other Research	Tier 2	Top LA	Non-Elite LA
Graduate Rate (%)	54.55	69.32	52.62	48.80	76.60	51.32

If graduation rates were the same across all tiers, we could expect the results of the empirical analysis to be simply scaled up in value when comparing between tiers. However, as seen in Table A.2, it is clear graduation rates do vary quite a bit between tiers, being lowest for Tier 2 and highest for Top Liberal Arts institutions.

Figure A.1 below, comparable to Figure 5.1 in the text, provides a means for comparing the impact of the varying denominators by tier. Here, I show the increase or decrease on the mean rate for each of the dependent variables, with and without controls.[83] Using the appropriate coefficient estimate, each bar shows a tier's impact on mean PhD productivity, relative to the non-elite liberal arts tier. Bars one and two in each category represent estimates absent controls using, respectively, enrollment and graduates as the base in the dependent variable. Bars three and four provide estimates with controls for the alternative outcome variables.

Figure A.1: Impact of Tiers, With and Without Other Explanatory Variables



Of interest in Figure A.1 is the change in ratios between the tier coefficients when a different measure of productivity is used. For example, previously Top Research was

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[83] I use the HS rank coefficients (columns 3a from the table) to measure ability for this comparison.

slightly more than triple Other Research (considering the without-controls results). Using the graduate denominator, however, the Top Research coefficient is slightly less than triple Other Research, presumably reflecting a higher graduation rate among top research universities – which is indeed the case. Thus selection, as reflected in graduation rates, explains some small or moderate portion of the Top Research to Other Research differential.

Additionally, and as discussed in the conclusion, over half of the tier effects can be attributed to other variables such as student and faculty characteristics. Here, we see the effect of using a different denominator. When comparing results from the two rates within a tier, the difference is minor.

For the two institution types with the highest output (Top Research and Top Liberal Arts), the effect on the mean is greater when using enrollment as the denominator. Using graduates as the denominator narrows the relative differences in the two largest PhD producing tiers, suggesting that some of the differences found reflect selection that is reflected in different graduation rates.

The tables presented in this Appendix are the results from two regressions from Chapter IV with the dependent variable defining output based on graduates instead of enrollment. Table A.3 is comparable to 4.6 and Table A.4 is comparable to Table 4.9.

Table A.3: Student and Faculty Characteristics, Controlling for Institution Type, 1990-2002[84]

	(3)a HS Rank	(3)b AP	(3)c SAT
Top Research	**7.241*****	**9.073*****	**7.690*****
	(1.158)	(1.265)	(1.249)
Other Research	**3.954*****	**5.377*****	**3.724*****
	(0.716)	(0.759)	(0.779)
Tier 2	**0.772***	**0.881****	0.438
	(0.394)	(0.397)	(0.461)
Top Liberal Arts	**9.050*****	**12.646*****	**10.116*****
	(0.948)	(1.047)	(1.015)
% Freshman top 10% HS	**0.127*****		
	(0.011)		
% Freshman top 10-25% HS	**0.026****		
	(0.012)		
% Freshman Bottom 50% HS	**0.026****		
	(0.013)		
% Freshman Taking AP in HS		**3.292*****	
		(0.888)	
25% SAT Verbal			**0.007*****
			(0.002)
75% SAT Verbal			**-0.016*****
			(0.003)
25% SAT Math			**0.013*****
			(0.003)
75% SAT Math			**0.014*****
			(0.004)
Top S&E Pubs per faculty	**3.736*****	**6.154*****	**5.179*****
	(1.247)	(1.382)	(1.327)
% FT Faculty With PhD	**0.034*****	**0.037*****	**0.035*****
	(0.006)	(0.006)	(0.007)
% Students in College housing	**0.030*****	**0.037*****	**0.034*****
	(0.006)	(0.006)	(0.007)
Average Age of freshman	-0.018	-0.047	-0.021
	(0.033)	(0.034)	(0.039)
% Minority (- Asian)	**-0.016***	-0.009	-0.002
	(0.008)	(0.009)	(0.009)
% International	-0.020	-0.006	-0.006
	(0.026)	(0.029)	(0.029)
Urban	-0.006	-0.004	-0.007
	(0.004)	(0.004)	(0.005)
Suburban	**-0.006****	-0.005	**-0.010*****
	(0.003)	(0.003)	(0.004)
State Unemp, Rate	0.072	0.068	-0.002
	(0.079)	(0.075)	(0.089)
NSF Stipend to Wage Ratio	**-0.331*****	**-0.309*****	**-0.372*****
	(0.045)	(0.043)	(0.049)
Observations	10,594	11,149	9,663
Institutions	1,022	1,035	905

Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

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[84] Censored: 35.9%, uncensored: 64.1% (mean rate = 9.97, mean rate (all) =6.39).

Table A.3a: Comparison of Effects on the Mean by Definition of the Dependent Variable

	Coeff (Enrollment)	Coeff (Graduates)	% from Mean (Enrollment)	% from Mean (Graduates)
% Freshman top 10% HS	0.024	0.127	1.7%	2.0%
% Freshman top 10-25% HS	0.004	0.026	0.3%	0.4%
% Freshman Bottom 50% HS	0.002	0.026	0.1%	0.4%
Top S&E Pubs per faculty	0.819	3.736	58.5%	58.4%
% FT Faculty w/PhD	0.007	0.034	0.5%	0.5%
% Students in College Housing	0.006	0.03	0.4%	0.5%
Average Age of Freshman	-0.002	-0.018	-0.1%	-0.3%
% Minority	-0.005	-0.016	-0.4%	-0.3%
% International	-0.001	-0.02	-0.1%	-0.3%
Urban	-0.001	-0.006	-0.1%	-0.1%
Suburban	-0.001	-0.006	-0.1%	-0.1%
State Unemp Rate	0.043	0.072	3.1%	1.1%
NSF Stipend to Wage Ratio	-0.082	-0.331	-5.9%	-5.2%

Nearly all variables remain unchanged in terms of sign and statistical significance. While the coefficients in tables A.3 and A.4 are much higher, due to the far higher scale of the dependent variable using graduates rather than enrollment in the denominator, what is of interest is their relationship to the mean rate for the given dependent variable. Table A.3a and A.4a show this relationship for each of the variables (tier coefficients are omitted from A.3a as they are shown above in Figure A.1).

As can be seen above, while the coefficients vary dramatically, the effects on the relative means is fairly consistent across the two dependent variables definitions. In addition, there is not a clear pattern in which is of greater magnitude. For instance, students coming from the top ten percent of high school have a greater effect on the mean when using graduates as the base, while the state unemployment rate has a larger impact when using enrollment as the base. The same is true for the results presented in Table A.4a.

Table A.4: HERI and College Board Variables, 1996[85]

	HERI +
% Freshman top 10% HS	0.250*** (0.030)
% Freshman top 10-25% HS	0.058* (0.034)
% Freshman Bottom 50% HS	0.057 (0.041)
Top S&E Pubs Per faculty	4.442** (2.076)
% FT Faculty w/PhD	0.122*** (0.021)
% Students in College housing	0.030** (0.015)
Average Age of Freshman	0.068 (0.093)
% Minority Students (-Asian)	-0.035 (0.027)
% International	0.021 (0.082)
Mother or Father w/ PhD/MD/JD	-0.010 (0.009)
Exposure to research index	-0.009 (0.007)
PhD planned: College Entry	0.032 (0.041)
PhD planned: BA Graduation	-0.236* (0.122)
Chose BA for ability to prepare students for grad school	0.223 (0.184)
Chose to attend college to prepare for graduate school	0.014 (0.208)
Faculty freq, encouraged grad school	-0.032 (0.069)
Frequently been a guest in a professor's home	-0.000 (0.083)
Observations	780

Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

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[85] Censored:32.3%, uncensored: 77.7% (mean rate = 10.04, mean rate (all) = 6.64).

Table A.4a: Comparison of Effects on the Mean by Definition of the Dependent Variable

	Coeff (Enrollment)	Coeff (Graduates)	% from Mean (Enrollment)	% from Mean (Graduates)
% Freshman top 10% HS	0.053	0.25	3.5%	3.8%
% Freshman top 10-25% HS	0.008	0.058	0.5%	0.9%
% Freshman Bottom 50% HS	0.006	0.057	0.4%	0.9%
Top S&E Pubs per faculty	1.273	4.442	83.8%	66.9%
% FT Faculty w/PhD	0.030	0.122	2.0%	1.8%
% Students in College Housing	0.006	0.030	0.4%	0.5%
Average Age of Freshman	-0.012	0.068	-0.8%	1.0%
% Minority	-0.003	-0.035	-0.2%	-0.5%
% International	-0.002	0.021	-0.1%	0.3%
Mother or Father w/ PhD/MD/JD	0.007	-0.010	0.5%	-0.2%
Exposure to Research Index	-0.030	-0.009	-2.0%	-0.1%
PhD Planned: College Entry	0.079	0.032	5.2%	0.5%
PhD Planned: BA Graduation	0.034	-0.236	2.2%	-3.6%
Chose BA for ability to prepare students for graduate school	-0.015	0.223	-1.0%	3.4%
Chose to attend college to prepare for graduate school	0.001	0.014	0.1%	0.2%
Faculty frequently encouraged graduate school	0.019	0.032	1.3%	0.5%
Frequently been a guest in a professor's home	0.046	0.000	3.0%	0.0%

Table A.5: Correlation Matrix

	Variable	A	B	C	D	E	F	G
A	Rate (Enrollment Base)	1.00						
B	Rate (Graduates Base)	0.96	1.00					
C	Top Research	0.27	0.26	1.00				
D	Other Research	0.03	0.04	-0.11	1.00			
E	Tier 2	-0.27	-0.27	-0.22	-0.26	1.00		
F	Top Lib Arts	0.39	0.35	-0.10	-0.12	-0.24	1.00	
G	Non Elite Lib Arts	-0.16	-0.14	-0.23	-0.27	-0.54	-0.25	1.00
H	% from Top 10% HS	0.64	0.60	0.34	0.10	-0.29	0.38	-0.22
I	% from Top 10-25% HS	-0.05	-0.03	0.02	0.09	-0.03	0.08	-0.09
J	% from Top 25-50% HS	-0.42	-0.41	-0.25	-0.13	0.19	-0.30	0.23
K	% from bottom 50% HS	-0.48	-0.45	-0.26	-0.08	0.25	-0.31	0.15
L	% Taking AP	0.55	0.50	0.37	0.09	-0.24	0.37	-0.28
M	25th% SAT V	0.40	0.37	0.18	0.07	-0.20	0.34	-0.17
N	75th% SAT V	0.35	0.32	0.15	0.10	-0.16	0.29	-0.17
O	25th% SAT M	0.47	0.44	0.24	0.15	-0.19	0.33	-0.26
P	75th% SAT M	0.41	0.38	0.21	0.15	-0.17	0.27	-0.23
Q	Top Pubs per Faculty	0.44	0.41	0.72	0.08	-0.20	-0.07	-0.22
R	% Faculty with PhD	0.43	0.42	0.30	0.14	-0.24	0.34	-0.25
S	% International	0.34	0.32	-0.12	-0.20	-0.28	0.40	0.22
T	Average Age of Freshman	-0.03	0.00	0.03	-0.02	0.01	-0.06	0.02
U	% Minority (minus Asian)	0.01	0.00	0.12	0.05	0.08	-0.04	-0.15
V	% Students on Campus	0.09	0.09	0.02	0.08	-0.06	0.07	-0.06
W	Urban	0.03	0.03	0.20	0.14	0.01	-0.07	-0.18
X	Suburban	-0.05	-0.06	-0.06	-0.07	0.10	-0.01	-0.02
Y	State Unemployment	0.06	0.06	0.00	0.03	0.07	0.01	-0.09
Z	NSF to Wage Ratio	0.10	0.11	0.00	0.00	0.00	0.00	0.00

	Variable	H	I	J	K	L	M	N
H	% from Top 10% HS	1.00						
I	% from Top 10-25% HS	0.01	1.00					
J	% from Top 25-50% HS	-0.70	-0.46	1.00				
K	% from bottom 50% HS	-0.76	-0.26	0.32	1.00			
L	% Taking AP	0.73	0.03	-0.52	-0.56	1.00		
M	25th% SAT V	0.52	0.15	-0.49	-0.37	0.54	1.00	
N	75th% SAT V	0.44	0.13	-0.39	-0.34	0.48	0.63	1.00
O	25th% SAT M	0.56	0.17	-0.50	-0.43	0.58	0.66	0.92
P	75th% SAT M	0.49	0.16	-0.44	-0.38	0.50	0.55	0.95
Q	Top Pubs per Faculty	0.50	-0.12	-0.28	-0.36	0.46	0.29	0.25
R	% Faculty with PhD	0.47	0.18	-0.47	-0.35	0.48	0.43	0.36
S	% International	0.34	0.03	-0.26	-0.25	0.25	0.33	0.26
T	Average Age of Freshman	-0.06	0.01	0.08	0.00	-0.05	-0.08	-0.07
U	% Minority (minus Asian)	0.07	-0.12	0.04	-0.07	0.06	-0.06	-0.01
V	% Students on Campus	0.10	-0.02	-0.03	-0.10	0.06	0.10	0.10
W	Urban	0.08	0.02	-0.06	-0.06	0.04	0.01	0.01
X	Suburban	0.02	0.04	-0.04	-0.02	0.04	0.03	0.05
Y	State Unemployment	0.08	0.01	-0.07	-0.05	-0.03	-0.26	-0.26
Z	NSF to Wage Ratio	0.01	-0.03	0.00	0.02	-0.13	-0.38	-0.45

	Variable	O	P	Q	R	S	T	U
O	25th% SAT M	1.00						
P	75th% SAT M	0.95	1.00					
Q	Top Pubs per Faculty	0.35	0.30	1.00				
R	% Faculty with PhD	0.47	0.40	0.29	1.00			
S	% International	0.29	0.24	0.02	0.27	1.00		
T	Average Age of Freshman	-0.09	-0.07	0.05	-0.04	-0.08	1.00	
U	% Minority (minus Asian)	-0.04	-0.04	0.14	-0.05	-0.20	0.01	1.00
V	% Students on Campus	0.07	0.08	0.07	-0.04	0.05	0.09	0.11
W	Urban	0.01	0.01	0.18	0.00	-0.24	-0.02	0.25
X	Suburban	0.06	0.05	-0.05	-0.07	0.03	-0.03	-0.05
Y	State Unemployment	-0.14	-0.14	0.00	-0.07	-0.03	-0.01	0.06
Z	NSF to Wage Ratio	-0.30	-0.29	-0.02	-0.07	0.04	-0.01	-0.10

	Variable	V	W	X	Y	Z
V	% Students on Campus	1.00				
W	Urban	0.14	1.00			
X	Suburban	-0.06	-0.56	1.00		
Y	State Unemployment	0.00	0.00	0.06	1.00	
Z	NSF to Wage Ratio	-0.06	-0.01	0.00	0.64	1.00

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Committee on the Status of Women in the Economics Profession

TECHNICAL SKILLS

Stata (proficient level)
Microsoft Office (proficient level)
EndNote (proficient level)
SAS (basic level)
MATLAB (basic level)