ACCOUNTING FOR DEGREE PRODUCTION LEVELS

IN ENGINEERING AND PHYSICAL SCIENCES

by

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(Under the Direction of James Hearn)

ABSTRACT

The production of engineers and scientists by American universities is one of the key factors in meeting the growing demand for skilled employees in these fields and in maintaining the country's competitiveness. Optimizing this degree production requires close examination of the factors that may influence the process. Several research works have been conducted on degree production at the institutional level; however, degrees are produced within fields/academic departments. This study examined the degree production of a sample of twelve AAU public universities in relation to variations in faculty instructional time allocation and faculty research expenditures at the field level (five fields of science and engineering: engineering, physical sciences, mathematical/computer sciences, life sciences, and social sciences) and the departmental level (in engineering and physical sciences). Degree quality was proxied by faculty compensation, and analyses were conducted at three award levels (bachelor's, master's, and doctoral) utilizing seemingly-unrelated regressions. Findings revealed that although tenured/tenure-track faculty still played a vital role at all award levels, other types of faculty (non-tenure-track faculty, part-time faculty, and teaching assistants) played an increasingly important role, especially at the bachelor's and master's levels. Significant differences were found among five fields of science and engineering and among various academic departments within engineering and physical sciences, and the patterns varied across the three award levels. Implications were important for both university administrators and federal and state policy makers, especially regarding the increasing importance of non-tenure-eligible and part-time faculty, their participation in academic governance, hiring choices to be made between non-tenure-track teaching faculty and tenured/tenure-track research faculty, and long-term effects of increasing funding for STEM fields in light of relative resource allocations to non-STEM fields such as the arts and the humanities. Due to limited data, other factors (faculty time allocated to research and service and faculty interaction time with students outside the class room), which could have had influence on the degree production process, were not assessed.

INDEX WORDS: Degree Production in Higher Education; Degree Production at Field Level; Degree Production at Departmental Level; STEM Fields

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CHAPTER 1

INTRODUCTION

The fact that scientists and engineers play a central role in American economic life cannot be argued. The American education process in sciences and engineering, a process built around intensive research experience for students, serves as a model for many countries. The production of scientists and engineers is critical to the achievement of national goals in two ways. First, postsecondary institutions are responsible for producing teachers and researchers in sciences and engineering. These are the teachers and researchers who also educate subsequent generations of scientists and engineers. Second, education in sciences and engineering contributes directly to national goals of technological and economic development, as the society increasingly is dependent on people with advanced knowledge in order to deal with issues such as reducing environmental pollution, combating hunger and disease, developing new sources of energy, and maintaining national competitiveness (Committee on Science, Engineering, and Public Policy, 1995, p. 11). Consequently, an understanding of factors that lead to effective production of scientists and engineers is critical to the economic development of the country.

Background

The current American system of education in sciences and engineering evolved from a series of policy decisions prompted by the increasing role of science and technology after World War II and during the Cold War. Among those decisions was the emphasis placed upon the role of universities: through a number of government agencies, the public would assume an important role in funding basic and applied research, and through this public funding, researchers at universities would become major contributors to the national scientific research effort. The universities would conduct basic research and at the same time provide graduate education in sciences and engineering as synergistic activities (Committee on Science, Engineering, and Public Policy, 1995, p. 12). These joint products—increasing scientific knowledge and producing scientists and engineers, which stemmed from educating students in the context of intensive research activities, allowed the American system of graduate education to

> “set the world standard for preparing scientists and engineers for research careers in academe, government, and industry. And by attracting outstanding students and faculty members from throughout the world, it has benefited from an infusion of both talent and ideas” (Committee on Science, Engineering, and Public Policy, 1995, p. 12).

This policy led to an expansion in scientific research and production of scientists and engineering during the Cold War period, as evidenced by the following numbers:

> The number of graduate science and engineering students increased roughly in parallel to the amount of federally funded scientific and engineering research from 1958 to 1988. Between 1958 and 1968, the number of PhDs awarded annually to scientists and engineers tripled to about 18,000. That swift growth lasted until the early 1970s, when national policy changes brought about the curtailment of most federal fellowships and traineeships. Thus, the annual production of science and engineering doctorates peaked at near 19,400 during 1971-1973 and fell to fewer than 18,000 during 1977-1985. The production of PhDs began to rise again in the late 1980s and reached 25,000 in 1993. Most of the net growth after 1985 was due to an increased number of foreign students with

> temporary student visas. (Committee on Science, Engineering, and Public Policy, 1995, p. 13)

Since the late 1980s, however, postsecondary institutions that conduct research and education in sciences and engineering have undergone a series of political, economic, and social changes. In part due to the end of the Cold War, but especially due to the growth of global economic competition, national attention has shifted from defense to economic, environmental, and other social concerns. Domestically, the U.S. is now challenged to produce better products and services in order to be more competitive in the global market; to find better ways to use natural resources; to discover new forms of energy; and to deal with crime, violence, and poverty. Internationally, the U.S. is concerned with finding solutions to limit population growth, to support emerging democracies, and to maintain national security and global economic health (Committee on Science, Engineering, and Public Policy, 1995, p. 16). More recently, in his speech on the "Educate to Innovate" Campaign and the Science Teaching and Mentoring Awards (January 06, 2010), President Obama emphasized the importance of these issues and their relationship with STEM education:

> Whether it's improving our health or harnessing clean energy, protecting our security or succeeding in the global economy, our future depends on reaffirming America's role as the world's engine of scientific discovery and technological innovation. And that leadership tomorrow depends on how we educate our students today, especially in math, science, technology, and engineering.

These changes have led to major shifts in university research funding. Defense spending for research has been cut, and industrial grants have been reduced and re-directed from basic research to projects that will serve their core businesses. State governments also tighten their budgets for higher education, with some public universities encountering absolute decreases of 20-25 %. Those financial changes and constraints have led to two major consequences for universities: they have used more of their own funds to support research projects, especially those considered to be long-term or risky, and they have reduced the numbers of scientific and engineering faculty employed and graduate students funded (Committee on Science, Engineering, and Public Policy, 1995, pp. 13-16).

All of these changes have posed an important dilemma: while funds for basic research and education in sciences and engineering have undergone considerable reductions, the demand for scientists and engineers has increased in a high-technology era. In short universities have come to play a more critical role than ever in developing the essential national work force. The National Science Foundation (NSF) 1996 report “Shaping the Future: New Expectations for Undergraduate Education in Science, Mathematics, Engineering, and Technology” points out the following:

> It is the conviction of this review committee that improved SME&T education is central to shaping America's future. The future will increasingly require that citizens have a substantial understanding of the methods and content of science and technology - and some understanding of their potential and limitations as well as their interconnectedness. (Background and Purpose section, para. 2)
>
> This is a powerful vision of an America of the future where every person has an opportunity for a life of economic security and personal satisfaction through pervasive learning that provides competence in scientific and technical

> fields. This vision derives from the conviction that SME&T learning has value for its own sake as well as powerful utility in the workplace and in the exercise of citizenship. (Background and Purpose section, para. 4)

More recently, Tolentino et al. (2005) affirm the importance of a highly-skilled work force in the globalized and knowledge-based economy and at the same time underscore the growing demand for scientists and engineers. They illustrate the above argument with the following figures:

> Specifically, employment in Science, Technology, Engineering, and Mathematics (STEM) fields during the current decade will increase three times faster than employment in all remaining occupations (National Science Board 2002). In addition, 25 % of scientists and engineers in the U.S. will be eligible for retirement in the year 2010. There has also been a long-term decrease in university undergraduate enrollment in math, physics, chemistry, and engineering majors (BEST report 2004). (Tolentino et al., 2005, p. 3)

These combined effects of global competition, continuous technological advances, scientific and engineering work force retirements, and reduced interests in STEM majors make it difficult for American universities to produce enough scientists and engineers to meet the growing demand for skilled employees in these fields. A fundamental national policy question is, in an era of reduced resources and increasing demands, how can universities educate more efficiently the large numbers of scientists and engineers that are required to meet the challenges of intensive international competitiveness?

Purpose of the Study

Given the importance of a skilled work force in STEM fields to maintain the national competitiveness, this study explores the production of bachelor's, master's, and doctoral degrees of a sample of AAU public universities at the field level (five fields of science and engineering: engineering, physical sciences, mathematical/computer sciences, life sciences, and social sciences) and the departmental level (in two fields of engineering and physical sciences) in relation to variations in faculty instructional time allocation and faculty research expenditures, controlling for quality of academic departments.

CHAPTER 2

LITERATURE REVIEW

We turn now to the literature that is most closely related to the purposes of this study: how universities and, in turn, their departments transform their resources into actions. This discussion begins with a study by Hasbrouck (1997), who examined how resources were transformed into expenditures by function (e.g., teaching, research, service) at the level of the university.

The data Hasbrouck (1997) used in this study came primarily from the Integrated Postsecondary Education Data System (IPEDS) and the Higher Education General Information Survey (HEGIS) finance and fall enrollment surveys. Carnegie classifications were obtained from reports published by Carnegie Foundation for the Advancement of Teaching. Two years of data were collected: fiscal year 1982-83 (FY83) using enrollment data from the fall of 1982, and fiscal year 1992-93 (FY93) using fall 1992 enrollment.

Hasbrouck (1997) found that there were positive relationships among revenue structures and expenditure patterns of public universities and that the former can explain the latter. Put another way, changes in revenue structures (funding bases) had impact on expenditure patterns (institutional priorities, i.e., actions) at the institutional level. By analyzing resource allocation both from the standpoint of real per-student expenditures and expenditure shares, several consistently significant and positive relationships were found to exist between governmental appropriations and instructions; between gifts, grants, and contracts and research; between tuition and fees and student services; between governmental appropriations and plant maintenance and operation; and between both tuition and fees, and gifts, grants, and contracts and scholarships and fellowships. Furthermore, these same positive relationships were found to persist when an explicit analysis of change over time was undertaken (p. 8).

Blasdell, McPherson, and Schapiro (1993) conducted their own analysis and found evidence that was consistent, to a large extent, with Hasbrouck's findings (1997). The data set that Blasdell, McPherson, and Schapiro used in their research consisted of financial and other information on colleges and institutions during the period, 1978-79 to 1988-89. This data set was merged from three smaller ones. The first—the Financial Statistics report from the Higher Education General information Survey (HEGIS) for the period up from 1978-79 to 1985-86, and the Integrated Postsecondary Education Data System (IPEDS) for the more recent period from 1986-87 to 1988-89—described the basic financial data of almost all public and private non-profit postsecondary institutions in the U.S. The second—the Fiscal Operations Report and Application to Participate (FISAP) data base—provided more detailed information on student aid spending and revenues and on the aided population at colleges and universities that applied for federal assistance under any of the "campus-based programs" (direct loans, Supplementary Educational Opportunity Grants, and college work study). The third—the HEGIS and IPEDS Enrollment Survey—reported full- and part-time enrollment for all institutions. This data set allowed the authors to estimate full-time-equivalent enrollment (FTE). All the financial data in this study were expressed on a per-FTE enrollment basis, adjusted for inflation, and presented in 1990-91 dollars (Blasdell, McPherson, & Schapiro, 1993, pp. 1-2).

Blasdell, McPherson, and Schapiro (1993) revealed several important findings. During the period from 1978-79 to 1988-89, in the private sector, the expenditure category that showed the largest per-student increase was physical plant and equipment (12.13 % per year), followed by unrestricted scholarships (7.32 %), public service (6.91 %), and academic support (5.09 %).

On the revenue side, gifts and endowment earnings rose at a very rapid annual rate over the entire period (8.69 %). On the same trend were net tuition and fees, which increased at a rate of 3.71 % per year (Blasdell, McPherson, & Schapiro, 1993, p. 8 & Tables 1 & 2).

In the public sector, the situation was more precarious. On the expenditure side, unrestricted scholarship, plant and equipment, research, and academic support were the categories that showed the largest annual percentage increases during the period, with the figures being 5.90 %, 5.35 %, 2.89 %, and 2.86 % respectively (Blasdell, McPherson, & Schapiro, 1993, Table 1). On the revenue side, although public universities were much more reliant on state and local appropriations than they were on any other revenue sources, state and local appropriations rose by only 0.98 % per year after adjusting for inflation. Federal grants and contracts, although being an important revenue source for public universities, also rose modestly during the same period (0.81 % per year). In contrast two important revenue categories for public universities—gifts and endowment earnings and net tuition and fees—increased by 3.11 % and 3.58 % per year, respectively. This meant that revenue from tuition and fees was the most likely means by which public universities were compensated for reductions in state and local appropriations. It also implied that the trend would continue in which public universities had become more dependent on tuition and costs to their students had risen at a rapid rate (Blasdell, McPherson, & Schapiro, 1993, pp. 9-10).

The findings of Blasdell, McPherson, and Schapiro (1993) suggested that shifts in revenue sources lead to corresponding shifts in expenditure categories. It is worth noting, however, that this pattern was clearer among private than public universities in the analysis.

In comparable work aimed at better explaining how revenues and expenditures interact in the operation of universities, Dolan and Schmidt (1994) modeled the input-output relationship for private undergraduate education, focusing on 80 Comprehensive Institutions and 281 General Baccalaureate Institutions, as defined by the National Center for Education Statistics (NCES).

The specific objective of this study was to identify the relative contributions of human and physical resources or “inputs” (including student quality, faculty quality, faculty-student ratio, physical plant, academic expenses, administrative expenses, tuition, and endowment) to the institutional production of undergraduate degrees, the “output.” On a conceptual level, the model developed in this study was noteworthy for its emphasis on interdependence among inputs in the production process. (Arguably, these “inputs” also could be considered “outputs.”) For example, the quality of the faculty was likely to be causally related to the quality of other institutional attributes (inputs) believed to contribute to the output, not the least of which was student quality. Therefore, undergraduate education, faculty quality, and student quality were treated endogenously (Dolan & Schmidt, 1994, p. 198).

The empirical results of the study revealed that the production of undergraduate degrees was dependent on various categories of human and physical resources that universities put into the production process. Specifically, the undergraduate degrees produced were significantly influenced by faculty quality, academic expenditure, and faculty-student ratio. Student quality was also important to the production of the institutional output although it was somewhat surprising that this variable was of only borderline significance. Perhaps the most conspicuous “non-result” was the apparent insignificance of the physical plant in relation to the output. Overall, the parameters in the model suggested a plausible, indeed traditional, recipe for undergraduate education—a relatively high ratio of quality faculty to good students in a study environment invested with adequate academic expenditure (Dolan & Schmidt, 1994, p. 204).

Analogous to the work of Dolan and Schmidt (1994), Ryan (2004) examined in detail the effects of institutional expenditure categories on student persistence and degree attainment. This study was based on a non-probability (i.e., nonrandom) sample of institutions using the Integrated Postsecondary Education Data System (IPEDS) Peer Analysis System, and the sample was of Carnegie Baccalaureate I and II Institutions in 1995.

In general, the results of this study seemed to confirm part of the general hypothesis that expenditures affected student persistence and degree attainment. The findings suggested that instructional and academic support expenditures produced a positive and significant effect on graduation rates (Ryan, 2004, p. 109). Student services expenditures, however, did not seem to have a positive and significant effect on degree attainment, as the hypothesis predicted. One possible explanation for this exception was that a large percentage of the student services might have been in admissions and financial aid service expenditures, which could have overshadowed the effects of expenditures of other services (Ryan, 2004, pp. 109-110).

The finding that academic support expenditures—which included academic administration and curriculum development, libraries, audio/visual services, and technology support for instruction—had a positive and significant effect stood in contrast to the insignificant effect of institutional support expenditures—which included general administration, such as the office of the president and the financial vice president. This suggested that all administrative and support expenditures might not have been of equal importance to student persistence and degree attainments. Although non-academic overhead and support costs might have been necessary "costs of doing business," the results indicated that keeping these expenditures to a minimum resulted in more resources for other expenditures more directly related to degree attainment (Ryan, 2004, p. 110).

The positive effect of institutional size on graduation rates was another interesting finding in this study: there appeared to be economies of scale for this sector of the higher education system. Relatively larger Baccalaureate institutions apparently were able to capture overall economies. How this played out in relation to considerations such as the breadth of curricula offered, class sizes, administrative configurations, and other institutional attributes was impossible to ascertain. In general, the study suggested that the categories one might have expected to be closely related to student involvement, engagement, experiences, and integration had the greatest effect on persistence and degree attainment (Ryan, 2004, p. 110).

Whereas Dolan and Schmidt (1994) and Ryan (2004) demonstrated the impacts of variations in institutional revenues and expenditures on the degree production process, Titus (2009) went one step further by investigating how selected financial aspects of state higher education policy influenced the production of bachelor's degrees within a state. His study used annual state-level panel data for 49 states over the period, 1992 to 2004. The data were drawn from various sources, including the Center for the Study of Education Policy (Grapevine), National Association of State Student Grant and Aid Programs (NASSGAP), National Center for Education Statistics (NCES), U.S. Bureau of Economic Analysis, the U.S. Bureau of Census' Current Population Survey of State Government Finances, and the U.S. Bureau of Labor Statistics.

This study revealed several major findings. Changes in tuition at four-year public institutions were negatively related to a change in per state appropriations to higher education institutions, lagged one year. This finding suggested that tuition at public four-year colleges and universities increased as state subsidies for higher education institutions declined (Titus, 2009, p. 458). Additionally, after controlling for the presence of private higher education (i.e., the undergraduate enrollment in private four-year institutions as a percent of total undergraduate enrollment in four-year institutions) and other variables within a state, increases in tuition at four-year public colleges or universities did not influence the production of bachelor’s degrees. Part of the explanation for this finding may have had to do with the overall political and financial climates of states having large private college components. In such states, state governments appeared to strive to maintain relative public-private differences in an effort to protect the private sector; they adjusted support of public colleges accordingly. Public institutions then adjusted their tuition prices as state support varied. Just how this played out in relation to public college graduation rates was not at all clear; however, it may have been simply that in such competitive environments state subsidy changes were not potent enough to impact public college graduation rates.

Titus (2009) also pointed out that after taking enrollment in private institutions into account, need-based financial aid per undergraduate enrollment had a positive influence on bachelor’s degree production within a state. These analytical results suggested that, controlling for the private higher education market, increases in need-based financial aid reduced the net price charged to students and resulted in an increase in the production of bachelor’s degrees (Titus, 2009, p. 458). This conclusion was consistent with previous studies which suggested that state need-based aid positively influenced enrollment in private higher education institutions

(Perna & Titus, 2004) and graduation from four-year colleges (Titus, 2006). The results of this study, however, revealed that the relationship between bachelor's degree production and state non-need-based financial aid was statistically insignificant. The lack of association between degrees produced and non-need-based aid was interesting, given the substantial growth in merit-based aid nationally since the advent of the Georgia Hope scholarship program in 1993. This finding could be explained as follows: because it was likely to be targeted on students who, even without receiving such aid, would have attended and graduated from college, state non-need-based tested aid did not appear to influence bachelor's degree production (Titus, 2009, p. 459).

The results of this study also demonstrated that bachelor's degrees production within a state was positively related to state appropriations for higher education, even after taking into account the endogenous nature of state support. This finding suggested that states that increased spending for colleges and universities, including private institutions, realized gains in the number of bachelor's degrees awarded per undergraduate enrollment (Titus, 2009, p. 459).

Studies summarized above clearly demonstrated that revenue sources, expenditure patterns, and state policies did influence the output of universities. These institutional level relationships, however, say little about the internal production processes, which occur largely within the "production units," i.e., academic departments. Put another way, institutional-level analyses are important as background, but there is little reason to believe that institutional-level financial dynamics are transmitted to the unit level in any straightforward way. This can be explained as follows.

First, academic departments are considered to constitute the fundamental organizational unit of colleges and universities. These units are generally the locus of decisions on the curriculum, academic degree standards, and the recruitment and promotion of faculty (Smart & Montgomery, 1976). Second, those academic departments are relatively autonomous although their interdependencies are increasingly visible in a period of decreasing organizational slack (Dressel & Simon, 1976). Although resource providers may be changing and resources may be reallocated accordingly at the institutional level, unless those changing dynamics are experienced at the production level, one might expect little in the way of organizational consequences. In fact, Stocum and Rooney (1997) report that even when resource consequences are experienced at the college level, effects can be buffered; "only when resources are brought to bear directly on expenditures at the unit (i.e., department) level do the advantages and disadvantages of revenue shifts play out, organizationally" (Leslie, Oaxaca, & Rhoades, 1999, p. 17).

The fact that academic departments are the fundamental unit of universities and are relatively autonomous in their operation necessitates unit-level analyses. We now begin with a discussion of the effects of resource dependency at the departmental level with a study from D'Sylva (1998).

D'Sylva (1998) investigated the interaction of revenues and expenditures in departmental operations, with data obtained from the Association of American Universities Data Exchange (AAUDE). Usable data were obtained for eight major, public Research universities, for a total of 200 departments in AY94 and six universities and 136 departments in AY96. D'Sylva supplemented the AAU data with information collected from AAU site visits. He also added program quality measures from the National Research Council's 1995 assessments and classified the departments into five fields of science and engineering, consistent with NSF categorizations.

D’Sylva (1998)’s major research questions were designed to address whether research has a greater weight than instruction in the departmental income production function, whether these weights had changed over a two-year period, and whether structural differences in the weights varied across five fields of science and engineering. His study revealed the following important results: among four fields of science and engineering (life sciences, engineering, physical sciences, and social sciences) and in five of eight cases, the 1994 and 1996 findings showed greater “returns” to teaching productivity, compared to research productivity, although returns to teaching did decrease between 1994 and 1996. D’Sylva was led to conclude that “The perception that instruction has been displaced by research as the priority in the allocation function of public universities was not supported by the results” (p. 165).

D’Sylva (1998)’s study also revealed that differences among the fields were informative. Only in the life sciences did his results show a greater return to research than to teaching. This seemingly reinforced the field-based observation that the degree of faculty entrepreneurship, as manifest in grant and contract work, was notably greater in the life sciences than in all the other fields. Also supportive of D’Sylva’s findings, the field visits cited very small amounts of research support available in the social sciences and substantial reductions in research funding in the physical sciences; very few such claims were heard in the life sciences and engineering. In D’Sylva’s results, the margin of difference favoring returns to teaching over research was greatest within the social sciences and physical sciences. In the field work, both of those fields were found to be farther removed from the competitive research environment than was the case for the life sciences and engineering. Leslie, Oaxaca and Rhoades (1999) concluded from D’Sylva’s work that relationships were quite stable within the social sciences and physical sciences, with faculty members seemingly going about their teaching and research activities in a fairly routine fashion, that the situation was somewhat less stable in engineering, and that it was organizationally dynamic or even unstable in the life sciences (pp. 22-23).

The D'Sylva (1998) study also found that "returns[1]" to undergraduate teaching productivity exceeded those to graduate teaching productivity in seven of eight cases and usually by large margins. In two cases, engineering and the physical sciences, the returns to graduate teaching were negative in 1994. These results, too, ran counter to the public, and even internal university perception, that graduate education was favored over undergraduate education among university priorities and in their patterns of resource allocation (Leslie, Oaxaca, & Rhoades, 1999, pp. 23-24).

In the last chapter of his doctoral dissertation, D'Sylva (1998) returned to the theoretical question: do the results support resource dependency or do they favor the economic theory of the firm? He seemed to favor the former (Leslie, Oaxaca, & Rhoades, 1999, p. 24); however, resource dependency at the departmental level in his study was not so straightforward as that at the institutional level in Hasbrouck's study (1997). This might have been because separating out departmental decisions in regard to resource allocation from those made outside departments was very difficult. Reflecting upon the two studies of D'Sylva and Hasbrouck; Leslie, Oaxaca, and Rhoades (1999) concluded that the allocation decisions that D'Sylva attributed to department choices were, at best, shared with agents external to the departments (p. 26).

In 1995, Gander also conducted an analysis on how academic departments of a university differed from each other in two major activities: teaching and research. Data used in this study were obtained from the University of Utah for three academic years, 1991-92 to 1993-94. The

[1] D'Sylva used this term loosely and without strict economic meaning.

University of Utah had about 70 departments, including 17 in the College of Medicine. Mainly because of data problems, the College of Medicine was excluded from the analysis. Of the remaining 53 departments, data were available for 31 departments, giving 90 observations for three academic years (pp. 314-315).

Gander (1995) took into account the fact that a university was a multi-product firm and specified that each academic department produced two outputs: teaching and funded research. Each output had its own production function and the same factor inputs because “a typical faculty member is assumed to do both teaching and research during the academic year. So, in effect, for a given year teaching and research can be treated as occurring simultaneously” (p. 312). Gander further assumed that measurement and decision errors in the inputs were not transmitted to the residuals; so the inputs were not correlated with the residuals, and treating the inputs as exogenous was vindicated (p. 313).

The study revealed several interesting findings. First of all, teaching productivity was lower among engineering and mines departments as compared to reference departments (social sciences, architecture, educational psychology, and social work). Also, there was no statistical difference in teaching productivity among departments in natural and health sciences as compared to the reference departments (Gander, 1995, p. 316). Second, faculty research productivity was significantly higher for departments in engineering and mines than it was for departments in the reference group. Departments in natural and health sciences also had significantly higher research productivity than departments in the reference group (p. 316). Third, the teaching and research productivity functions, for the relatively short period studied, were independent of time. This meant that time-related factors, on average, did not significantly influence faculty teaching and research productivity (p. 316). Fourth, the two productivity functions--teaching and research--were statistically independent of each other. In other words, random forces that affected teaching productivity did not simultaneously affect research productivity and vice versa (p. 316). This meant “For any given time period, both output productivities could be up or down or one up and the other down. There is no expectation that randomly high research performance will occur jointly with randomly high teaching performance” (p. 318).

Also examining the operation of academic departments, Ward (1997) conducted an analysis using the University of Delaware’s 1994 NSICP (National Study of Instructional Costs and Productivity) data files in order to examine the influence of various expenditure categories on degree production. The files yielded usable data on faculty members, student credit hours, and class sections offered by 93 departments in 27 Research I and II Universities, for a total of 955 observations. Ward focused exclusively on the undergraduate level, citing evidence that the contemporary policy focus and the public concern were on undergraduate education (Ward, Chapter 1).

Specifically, Ward (1997) posed the following questions: do departments having greater research expenditures per faculty member and as a percent of total spending vary in regard to undergraduate student credit hour production and number of class sections taught? How do any of these variations play out in regard to the distribution of the undergraduate teaching among the faculty of differing types, e.g., tenure/tenure-track, adjunct, teaching assistant? Are there differences by academic field? Are there differences by institutional sector, public and private? Overall, Ward concluded that within-departments instructional variables were far more important to explaining instructional productivity than was the volume of research activity: “With regard to the number of undergraduate student credit hours taught per instructor, it appeared that tenure/tenure-track faculty were more responsive to changes in the share of instructors (percent of tenure/tenure-track faculty within the department) and to instructional spending variability" (p. 132).

More importantly, the lack of evidence found by Ward (1997) in support of effects of variations in one resource—research—at the departmental level suggested either that no such effects occurred or that they occurred at other organizational levels. Clearly, departmental research revenues did not appear to influence the undergraduate teaching conducted in departments, on average, although nothing could be said from Ward's study about the quality of the teaching effort. "From Ward's study, it could be concluded that if a department engaged in research, it was not at some cost to the amount of undergraduate instruction produced. Perhaps, on the whole, revenue stress was not experienced at the unit level, and they were sought for other purposes such as prestige maximization" (Leslie, Oaxaca, & Rhoades, 1999, p. 19).

Also examining the production process of universities at the academic-unit level, Dundar and Lewis (1995) conducted a study on cost function of university departments in three fields: social sciences, physical sciences, and engineering. The major source of departmental data for this study came from the statistics gathered every two years by the American Association of University Data Exchange (AAUDE, 1990) from thirty-eight participating institutions. Data on expenditures (costs) and teaching outputs (student credit hours at the three instructional levels of undergraduate, master, and doctorate programs) were drawn from the latest complete AAUDE data set (i.e., 1985-1986).

This study took into account the fact that universities were multi-product firms. Therefore, outputs of the joint production of teaching (undergraduate teaching, master-level teaching, and doctorate-level teaching) and research were examined (Dundar & Lewis, 1995, p. 120). Additionally, Dundar and Lewis (1995) underlined the importance of doing analysis at the departmental level, because both tangible and intangible output differences existed between fields, especially at large research-oriented public universities (p. 122). Another notable feature of this study was that attempts were made to control for quality variation in outputs that might have existed within the production of differing departments. Furthermore, because it could be argued that the underlying production technology facing each department even within related fields might have been different, this potential problem was tested statistically by the use of department-specific dummy variables (Dundar & Lewis, 1995, p. 122).

Overall, the study showed the following major results: inclusion of departmental quality and departmental measures did not appear to affect the explanatory power of the basic multiproduct model. [However, in the case of the physical sciences there did appear to be significant differences in departmental costs among Departments of Computer Science, Chemistry and Physics and the other departments within the physical sciences (Dundar & Lewis, 1995, p. 134).] Nevertheless, this did not necessarily suggest the insignificance of output quality. Rather, this insignificance should be interpreted as more likely resulting from our relatively homogeneous sample of universities, since all the institutions in the sample are comparable public research universities (Dundar & Lewis, 1995, p. 142).

As far as the costs of production were concerned, this study revealed that the costs of providing instruction at advanced levels (particularly at the doctoral level) were not necessarily the highest within each field. This contradicted the conventional wisdom and findings of most previous cost studies: that the costs of instruction would necessarily increase by level (e.g., graduate education costs more than undergraduate education, with doctoral education costing the most) (p. 142). The findings of this study indicated, for example, that in the social sciences doctoral training was less costly at the margin than master's-level education. This was because in social science departments most doctoral students were employed as undergraduate teaching assistants (Dundar & Lewis, 1995, p. 136).

Related to the finding above, this study also supported the commonly understood (but seldom empirically verified) notion that the departmental costs of producing graduate education along with undergraduate teaching, and the departmental costs of producing graduate education along with research, were significantly less than producing them separately (Dundar & Lewis, 1995, pp. 142-143). This can be explained as follows. On one hand, the utilization of doctoral students as undergraduate teaching assistants led to cost effectiveness, or cost complementarity, in the joint production of undergraduate and doctoral teaching in some departments: there did exist a joint supply effect for producing undergraduate ad doctoral students in the social sciences. On the other hand, the study did not find such cost complementarity between undergraduate teaching and doctoral teaching in the physical sciences and engineering, which suggested that departments in those two fields did not use graduate students as much as social science departments in the production of undergraduate teaching (Dundar & Lewis, 1995, p. 136).

Cost complementarity also existed in the joint production of graduate teaching and research. Such cost complementarity was found in the physical sciences and engineering. A reason for this was that in the physical sciences and engineering the use of graduate students as research assistants was intense (Dundar & Lewis, 1995, p. 136), whereas such complementarity was greatly less in the production of graduate teaching and research in social science departments because graduate students in the social sciences were primarily employed as teaching assistants, as already explained above.

In 1992 Nelson and Hevert examined cost structures at different enrollment levels. A major finding was consistent with the finding of Dundar and Lewis (1995): costs to educate students varied at different enrollment levels. Nelson and Hevert used departmental data obtained from the Office of Institutional Research at the University of Delaware for 31 different academic departments during the period of 1979-83. The use of data from only one university over a period of time allowed the authors "to control for differences in enrollments, average class size, research intensity, and input prices across departments" (Nelson & Hevert, 1992, p. 474). Total educational costs of each department were defined as the sum of "expenditures on professional, faculty, graduate teaching assistant, and staff salaries, miscellaneous wages, supplies and expenses, occupancy and maintenance, equipment, information processing and other miscellaneous expenses" (Nelson & Hevert, 1992, p. 476). To allow for differences in the costs of education at various levels of instruction, three different educational outputs were defined for lower-level undergraduate, upper-level undergraduate, and graduate students. Two additional variables were also included in the model to capture differences in educational technology across departments: the first variable represented the average class size, and the second represented the primary method of instruction in a department (laboratory vs. lecture classes) (Nelson & Hevert, 1992, pp. 474-475).

The analysis of Nelson and Hevert revealed an important finding: measured at the (data) mean, the elasticity of marginal cost with respect to class size for lecture classes was –0.426, –0.303, and –0.129 for lower-level undergraduate, upper-level undergraduate, and graduate students, respectively. The corresponding estimates for laboratory classes were –0.483, –0.303, and –0.119, respectively. Those figures implied that marginal costs rose with the level of instruction, as expected (Nelson & Hevert, 1992, pp. 480-481). Another related finding was that at the same level of instruction, laboratory classes were generally more expensive than lecture classes. The ratio of marginal costs between laboratory and lecture classes was 1.20, 1.45, and 2.61 for lower-level undergraduate, upper-level undergraduate, and graduate students, respectively. “These results are consistent with those presented in Verry and Layard (1975) and Verry and Davies (1976), who report significantly higher marginal costs for science and engineering courses” (Nelson & Hevert, 1992, p. 481).

The works of D’Sylva (1998), Gander (1995), Ward (1997), Dundar and Lewis (1995), Nelson and Hevert (1992), and Leslie, Oaxaca and Rhoades (1999) above demonstrate two important points: first, resource dependency does hold at the departmental level, but to a lesser extent than at the institutional level. At least this is the conclusion of D’Sylva (p. 168) and Leslie, Oaxaca and Rhoades (p. 27), who conclude that resource dependency effects are mitigated greatly at the department level. Second, the degree production process does vary by academic department and field of science and engineering.

CHAPTER 3

THEORETICAL FRAMEWORK

National and corporate competitiveness are issues that are attracting policy makers' attention, and neo-classic economic theory is often used as the starting point for explaining the competitiveness of a country or a firm. According to this theory, three factors of production account for macro economic conditions and growth: land (e.g., natural resources), capital (financial resources, human-made tools and equipment), and labor (quantity and quality of the workforce). For policy purposes labor generally is seen as the most important of these factors because it usually is most easily manipulated whereas natural resources and capital are seen, in relative terms, as "givens." Labor is the means by which land and capital are employed in the production process.

Neo-classic economic theory is built on the concept of diminishing returns. Samuelson (1976) presents this concept as follows: an increase in some inputs relative to other fixed inputs will, in a given state of technology, cause the total output to increase; "but after a point the extra output resulting from the same additions of extra inputs is likely to become less and less" (p. 27). This diminution of the extra output is a consequence of the fact that, after a point, new injections of varying resources will result in the fixed resources declining relative to the increasing variable inputs, hence lowering productivity and causing diminishing returns. It should be noted here that the law of diminishing returns holds only when one input is fixed and the other input is increasing. For example, if one has a particular fixed area of land, the addition of more and more labor will result in diminishing returns to each additional unit of labor. In contrast if both land and labor increase at the same rate, there may be no diminishing returns. Instead, there may be "constant returns to scale," that is no diminishing returns since all production factors increase equally and all economies of large-scale production have already been realized (Samuelson, 1976, p. 453ff). When economies of scale are realized, an across-the-board increase in the production factors will result in increasing, not decreasing, returns.

With the law of diminishing returns in operation, Clark (1899) claims that labor and capital (two major production factors in the modern economy) generate income from what they have contributed to the production process. For example, if L units of labor are employed in the economy and each unit is paid a wage w, then the income of laborers (i.e., the owners of labor) is w x L. Similarly, if K units of capital are employed and paid a return r, then the income of capitalists (i.e., the owners of capital) is r x K. If Y is denoted as the total output of the economy, then the income shares of labor and capital can be expressed as (w x L)/Y and (r x K)/Y, respectively. Therefore, we can know how much labor and capital, in the national aggregate, contribute to the economy simply by finding out how much income each of those production factors generate, in the aggregate. Clark notes that this model does not apply if diminishing returns do not exist. If there are constant returns, then there is no point at which returns to labor or capital are just equal to their costs, respectively. If there are increasing returns, then no matter how much labor or capital is added to production, the next additional unit of those factors will earn more returns. Only when there are diminishing returns can we find one level of output that matches the cost of a production factor. This level of output is the unique solution to the problem of price determination.

However, in 1956 Abramovitz found out an instance that could not be explained by neo-classic economic theory. He analyzed the aggregate economic data for the United States for the period from the 1870s to the early 1950s and found that the net national product per capita grew by approximately 400 % in this period. According to neo-classic economic theory as explained above, each factor of production must have generated income proportional to the output it had contributed to the economy. The income of capital, defined mainly as profit and interest, constituted only between one-third and one-fourth of the national income. Labor, in the form of wages and salaries, generated the rest. According to Abramovitz's figures, capital per person had tripled (measured in constant dollars) while the number of man-hours per person had gone down by 6 %. Since labor's contribution to the total output appeared to be about three times the contribution of capital, Abramovitz calculated that the weighted increase of the production factors—capital and labor—was equal to 1.14. In other words, the output per capita should have increased only slightly in this period, not by 400 %. From those findings Abramovitz remarked that almost the entire increase in net output per capita seemed to be associated with a rise in productivity (p. 11). Put in other words, more output was produced from the same amount of inputs. Abramovitz also came to the following conclusion:

> This result is surprising in the lopsided importance which it appears to give to productivity increase, and it should be, in a sense, sobering, if not discouraging, to students of economic growth. Since we know little about the causes of productivity increase, the indicated importance of this element may be taken to be some sort of measure of our ignorance about the causes of economic growth in the United States and some sort of indication of where we need to concentrate our attention. (p. 11)

This “measure of our ignorance” (or “residual,” “technological progress,” “total factor productivity,” or “technical change,” as various people call it) and its causes have never been explained adequately by neo-classic economic theorists (Rynn, 2001, pp. 67-68). This necessitates a new theory for explaining macro-economic patterns of growth. At the same time, this theory should provide stronger basis for analyzing processes involved in technical change (Nelson & Winter, 1982). Co-evolutionary theory of economic growth is one theory that satisfies the above conditions, as it offers an explanation of how economic systems evolve and become relatively more or less competitive.

Co-evolutionary economic theorists view firms as operating in an always-changing economic context that cannot be fully predicted or understood. Firms are regarded as engaging in searching for response to disequilibrium, with no presumption that the industry is at equilibrium (Nelson & Winter, 1982). This searching process is co-evolutionary and can be explained in greater detail as follows. First, the process begins with a set of possible solutions to a problem, the process selection mechanism being defined as testing these solutions against the original problem and evaluating how well they can solve it. Second, the worst solutions are eliminated and the better solutions are replicated. These two steps, selection and replication, produce a set of solutions; however, because they are limited by the set of starting candidates, they will not be necessarily the best solutions. By adding a third mechanism—variation—the best possible solutions may be realized. The mechanism of variation takes the good solutions, modifies them to generate new candidate solutions, and begins the process again. This is in itself a co-evolutionary process: selection tests solutions against problems; replication carries out solutions and updates problems; and variation generates new solutions. In a co-evolutionary economic process, it is knowledge or innovation (new ideas and ways of doing things) that evolves and is subject to selection, replication, and variation. The growth of knowledge, or innovation, ultimately underpins the wealth of nations (Potts, 2003).

In comparison with neo-classical economic theory, co-evolutionary theory sees the economy as always in the process of change, with economic activities always proceeding in a context that is not completely familiar to the actors, or perfectly understood by them. In contrast neo-classical theory sees the economy as at rest, or undergoing well-anticipated changes in a context that decision makers have observed through relevant experience, or can calculate accurately based on what they know thoroughly (Nelson, 2007).

This difference in the way economic context is interpreted leads to several important operational differences. Although both co-evolutionary and neo-classical theories assume that economic actors pursue reasonable objectives, co-evolutionary theorists see the rationality of the economic actors as bounded. That is, there is no way for them to understand fully the context in which they are operating. Dealing with this uncertainty involves the use of routines that have yielded satisfactory results in the past; however, economic actors in co-evolutionary theory also have the capability to innovate if they see an opportunity, or when what they have been doing becomes inadequate in a changed context. In contrast neo-classical theorists assume that economic actors face given and fully understood choice sets, and make optimal choices given those sets. This assumption might make sense if one could assume that the economic context is basically unchanging, that economic actors have learned sufficiently what works and what does not in that context, and that there is sufficient time to filter out or transform incompetent behavior. In most cases, however, this assumption is invalid because the economic context tends to be changing; therefore, what was sufficient in the past may not be adequate in the present.

Additionally, assuming that the economic context is static ignores the fact that economic actors can and do behave in innovative ways (Nelson, 2007).

Co-evolutionary and neo-classical economic theories also differ in their explanations of economic performance. Neo-classical theorists judge economic performance in terms of how close it is to a theoretical optimum. In contrast co-evolutionary theorists propose that there is no theoretical optimum since the possible range of economic actions is always changing and cannot be predicted in full. Economic performance should be seen in terms of the rate and nature of progress, and economic progress should be understood as a learning process (Nelson, 2007).

Another significant difference between the two theories is the ways they view economic development. Neo-classical theory sees economic development as largely driven by accumulation—investments in physical and human capital. Countries behind the production-possibility frontier that have made successful progress in closing the gap have been marked by high rates of investment in physical and human capital. Neo-classical theory proposes that if investments are made, the acquisition and mastery of new ways of doing things are relatively easy, even automatic. In contrast co-evolutionary theorists argue that investments in physical and human capital are needed to bring in new ways of doing things, but they are not sufficient. The driving force of successful "catching-up countries" involves bringing in and learning to master ways of doing things that may have been used for some time in more advanced economies of the world even though these "ways" are new for the catching-up countries or regions. This process requires considerable learning in order to put the new knowledge under effective control (Nelson, 2007). Fostering economic development in a country, however, relies not only on firms but also on the higher education system, as Nelson (2007) points out below:

> There is no question in my mind that for countries aiming to catch up, developing the capabilities for learning and innovation in firms is the heart of the challenge. However, a strong system of university and public labs research can play a very important supporting role. (p. 20)

Helping to explain how organizations respond to their environments and evolve competitively, resource dependency theory focuses on those who provide financial and physical support to an organization and how they influence its operation. Pfeffer and Salancik (2003) state the following:

> The key to organizational survival is the ability to acquire and maintain resources. This problem would be simplified if organizations were in complete control of all the components necessary for their operation. However, no organization is completely self-contained. Organizations are embedded in an environment comprised of other organizations. They depend on those other organizations for the many resources they themselves require. Organizations are linked to environments by federations, associations, customer-supplier relationships, competitive relationships, and a social-legal apparatus defining and controlling the nature and limits of these relationships. (p. 2)

Understanding an organization's environment is, therefore, essential to understanding its behavior because an organizational operation depends not only on internal factors (structure, leadership, and procedures) but also on external ones (resources and associated constraints) and the interaction among them. As Pfeffer and Salancik (2003) point out, "in social systems and social interactions, interdependence exists whenever one actor does not entirely control all of the conditions necessary for the achievement of an action or for obtaining the outcome desired from the action" (p. 40). Interdependence is a consequence of the "openness" nature of organizations. They must transact with elements of the environment in order to acquire resources needed for survival.

There are a few points that should be noted here. First, interdependence is not necessarily symmetric or balanced. It can be asymmetric with an organization being more dependent on other organizations for its resources. Moreover, interdependence need not be either competitive or symbiotic. Relationships frequently contain both forms of interdependence simultaneously. Second, the degree of interdependence among organizations is not static but varies over time together with their co-evolution. As organizations become more self-contained, there is less interdependence among them and vice versa. The magnitude of interdependence also varies with the availability of resources relative to the demand for them. When a resource is scarce but the demand for it is high, the interdependence among related actors increases and vice versa. Third, interdependence can create problem of uncertainty or unpredictability for organizations, and trying to solve this problem is likely to increase the interdependence among them. This can be explained as follows. Lack of coordination of activities among interdependent organizations often leads to uncertainty, and organizations attempt to cope by restructuring their transaction relationships and make behaviors more predictable for each. However, this solution involves increasing coordination among organizations, which may lead to more interdependence among them (Pfeffer & Salancik, 2003).

Interdependence is important because of its impact on the ability of the organization to achieve its goals. However, this need to depend on the environment for necessary support leads to a consequence: in order to continue providing what the organization needs, external organizations may demand certain actions from the organization in return. Pfeffer and Salancik (2003) point out that “it is the fact of the organization’s dependence on the environment that makes the external constraint and control of organizational behavior both possible and almost inevitable” (p. 43). It should be noted that because demands from the external organizations are different, they often conflict with one another: responding to the demands of one group constrains the organization in its future actions, including whether and to what extent future responses to other groups should be made. Put simply, the organization cannot respond to every environmental demand completely. Instead, it must decide “which group to attend to and which to ignore” (Pfeffer & Salancik, 2003, p. 27). An understanding of factors that determine the dependence of an organization on another is, therefore, critical to the understanding of organizational behavior.

The first factor that influences the dependence of an organization on its environment is the importance of a resource. There are two components of this importance: the relative magnitude of the exchange and the criticality of the resource. The relative magnitude of an exchange is measured by assessing the proportion of total inputs or the proportion of total outputs accounted for by the exchange, whereas the criticality of the resource is defined as the ability of the organization to continue functioning in the absence of the input or in the absence of the market for the output. It should be noted that a resource may be critical to an organization even though it comprises only a small proportion of the total input. The criticality of a resource to an organization also may vary over time as conditions in the organization’s environment change. That a resource is important to an organization is, in itself, not a source of the organization’s problems. It is the uncertainty of the environment in providing resources to the organization that causes problems, and one of the management's responsibilities is "to minimize the possibility of resources becoming scarce or uncertain" (Pfeffer & Salancik, 2003, p. 47).

The second factor that determines the dependence of an organization on others is the degree of discretion over the allocation and use of a resource possessed by others. There are many forms of discretion over a resource; and in an environment full of interdependent actors, there is rarely absolute discretion. It is more common that "there are degrees of shared discretion" (Pfeffer & Salancik, 2003, p. 48). One basis for control over a resource is possession. An organization is able to maintain its possession of a resource only when legal and social foundations permitting its ownership exist. Although possession is a basis for controlling a resource, it is not absolute and depends on the consent of others in the social system. Another basis for control is access to a resource. It is possible to regulate this access without possessing it. Any entity that can influence the allocation of a resource has some degree of control over it. One more important basis for control is the actual use of a resource and who controls its use. It is possible for a resource to be used by others than the owners. In this case, the users have some control over the resource. The last source of control over a resource is from the ability to make and enforce rules regulating the possession, allocation, and use of a resource. The ability to make and enforce rules also determines the extent to which dependence relations, developing from resource exchanges, can be used to achieve external control of organizational behavior (Pfeffer & Salancik, 2003).

The third factor that determines the dependence of an organization on its external environment is the concentration of resource control, which refers to the degree to which an important resource is controlled by a relatively few, or even only one, significant organization(s).

This is a critical factor because organizations controlling an important resource must also be able to exercise some control over alternative suppliers of the same resource if they want to create a dependence relationship with the focal organization. In that sense there are a number of ways that can give rise to concentration of resource control. For example, an organization can have a monopoly position legally protected and established, as in the case of electric and telephone utilities; or a group of corporations can pool their resources and form a cartel (Pfeffer & Salancik, 2003).

The three factors above work together in defining the dependence of an organization on its external environment: dependence is the product of the importance of a given resource (input or output) to an organization and the extent to which it is controlled by a relatively small number of organizations. A resource that is not important to an organization cannot create dependence no matter how concentrated the control over the resource is. Also, no matter how important a resource is to an organization, unless it is controlled by a relatively few organizations, the focal organization will not be particularly dependent on any of them. In other words, “when there are many sources of supply or potential customers, the power of any single one is correspondingly reduced” (Pfeffer & Salancik, 2003, pp. 51-52).

Resource dependency theory offers a view of organizations that may be seen as both alternative and complementary: from the standpoint of traditional organizational theories, decision-making processes of organizations are mostly controlled internally whereas resource dependency theory views the same processes as influenced primarily by external factors.

Collectively and progressively, these three theories serve as bases for explaining generally how national competitiveness is achieved through the actions of organizations and their internal units and specifically the role of universities and their departments in contributing to national economic growth through improvements in the quality of labor as indicated by the degrees they produce.

CHAPTER 4

RESEARCH QUESTIONS AND SIGNIFICANCE OF THE STUDY

Given the importance of STEM education in the economy, this study examined the degree production processes (bachelor's, master's, and doctoral) of research universities at two levels: a) field level (five fields of science and engineering: engineering, physical sciences, mathematical/computer sciences, life sciences, and social sciences) and b) departmental level (in two fields: engineering and physical sciences) in relation to variations in production function variables: faculty instructional time allocation, faculty research expenditures, and faculty compensation. The two following research questions were proposed:

Research question 1: Holding degree quality constant, to what degree do faculty instructional time allocation and faculty research expenditures explain the number of degrees awarded by degree production level (bachelor's, master's, and doctoral) in five fields—engineering, physical sciences, mathematical/computer sciences, life sciences, and social sciences?

Research question 2: Holding degree quality constant, to what degree do faculty instructional time allocation and faculty research expenditures explain the number of degrees awarded by degree production level (bachelor's, master's, and doctoral) in academic departments within two fields—engineering and physical sciences?

Findings related to those research questions were expected to make meaningful contributions to the understanding of how departments utilized their resources to produce degrees; and focusing on the departmental level was critical because both production functions and outputs varied importantly across departments, a point that had been supported by the literature. A specific example of a result might be, "At the sample mean and holding degree quality constant, a 10 percent rise in research expenditures per FTE faculty is associated with a 2.3 percent drop in undergraduate degree production in the department of civil engineering."

From their better understanding of the degree production process, university-level administrators would gain insights in regard to allocating resources among departments, and departments might learn how best to utilize their resources to produce degrees more effectively and efficiently. It had long been agreed that one of the most important and desirable outputs of universities was well-trained graduates who contributed importantly to the National Income and the country's successful competitiveness in the international arena.

The findings of this study would also have practical implications for numerous groups, such as external policy makers, university administrators, and potential donors. For example, the study results might aid federal and state policy makers in targeting financial aid, appropriations, and research grants in engineering and physical sciences.

CHAPTER 5

DATA AND ASSUMPTIONS

Data

Data for this dissertation were from an NSF-fund project (No. 08-520), which was co-investigated by Profs. Larry Leslie and Sheila Slaughter (University of Georgia, Athens), and Liang Zhang (Pennsylvania State University). The data were purchased from the Office of Institutional Research and Planning, the University of Delaware and were part of the Delaware Instructional Costs Study that spanned over three years 2005, 2006, and 2007. In this data set, there were totally 12 participant universities in the study (Table 1), all of them being AAU public universities.

Table 1. Participation of Twelve AAU Public Universities in the 2005-2007 Delaware Instructional Costs Study

Name	2005	2006	2007
Iowa State University		x	x
SUNY-Stony Brook		x	x
SUNY-Buffalo	x		x
University of Arizona		x	
University of Colorado at Boulder	x	x	x
University of Kansas	x	x	x
University of Missouri-Columbia	x	x	x

University of Nebraska-Lincoln	x	x	x
University of North Carolina-Chapel Hill	x	x	x
University of Oregon	x	x	x
University of Texas at Austin	x	x	x
University of Wisconsin-Madison	x	x	x

Each record in the data set contained detailed information of an academic department of a public research university in three categories: numbers of degrees granted, faculty instructional time allocation, and financial resources. The degree data were reported at four different production levels—bachelor's degrees, master's degrees, doctoral degrees, and professional degrees—and were coded by reporting academic departments according to the four-digit Classification of Instructional Programs 2000 (CIP 2000). In order to group those academic departments into five fields of science and engineering (engineering, physical sciences, mathematical/computer sciences, life sciences, and social sciences), a crosswalk between NSF fields of science and engineering and the National Center for Education Statistics (NCES) Classification of Instructional Programs was used (Appendix 1).

The instructional time allocation data were originally divided into five faculty categories: tenured/tenure-track faculty, other regular (non-tenure-eligible) faculty, supplemental (part-time) faculty, (credit-bearing) teaching assistants, and (non-credit-bearing) teaching assistants. (Other regular faculty consisted of clinical/research/visiting faculty, instructors, lecturers, and senior lecturers. Supplemental faculty consisted of part-time/hourly part-time faculty and summer assignment of nine-month faculty.) In each of the above five faculty categories, detailed information for fall semester each year was available for total instructional FTE faculty, total separately-budgeted faculty, total FTE faculty (sum of total instructional FTE faculty and total separately-budgeted faculty), undergraduate lower-division student credit hours (SCH) and organized class sections (OCS), undergraduate upper-division SCH and OCS, undergraduate individualized instruction SCH, graduate SCH and OCS, graduate individualized instruction SCH, and labs OCS. Besides those fall-semester numbers, annual total undergraduate and graduate student credit hours were reported.

The annual financial data included faculty salaries, faculty benefits, **“**other than personnel expenditures,**”** total direct instructional expenditures (sum of faculty salaries, faculty benefits, and other than personnel expenditures), separately-budgeted research expenditures, and separately-budgeted service expenditures.

The focus of this dissertation was on degree production of those 12 AAU public universities at three degree production levels (bachelor’s, master’s, and doctoral), in relation to variations in time allocation (lower-division undergraduate, upper-division undergraduate, and graduate student credit hours) of four major types of faculty (tenured/tenure-track faculty, other regular faculty, supplemental faculty, and credit-bearing teaching assistants), and under the effects of two major financial categories (faculty compensation and separately-budgeted research expenditures) over the three-year period (2005-2007) of the available data. Other data in the files were omitted due to missing data (separately-budgeted service expenditures) or their lesser importance (non-credit-bearing teaching assistants).

Assumptions

Several assumptions were made for this study. The first assumption was that data reported by academic departments correctly reflected what had actually happened in those departments, or that the bias—"preference falsification"—was systematic.

A second assumption was that the number of student credit hours taught by each faculty type acted as a proxy for the time the faculty had actually spent on teaching bachelor's, master's, and doctoral students, and that this in-class instructional time reflected the faculty's commitment to teaching. Unfortunately, the amount of instruction-related time spent outside the classroom was not available from the 2005-2007 Delaware Instructional Costs Study.

The third assumption was that the availability of only fall semester faculty instructional time allocation (broken down by faculty type) did not affect results importantly. Annual total student credit hours for all faculty types, however, were reported, and annual student credit hours taught by each faculty type could, therefore, be projected by assuming that student credit hours taught by each faculty type did not vary significantly between fall and spring semesters. (Even if variation did occur from semester to semester by individual faculty members, mean student credit hours taught by each faculty type in an academic department tended to be evenly distributed between these two semesters of the year.) With this assumption, annual student credit hours taught by each faculty type were projected by multiplying student credit hours taught by each faulty type in fall semester by the ratio of annual over fall-semester student credit hours.

CHAPTER 6

STATISTICAL METHODS AND MODEL SPECIFICATION

The production relationship in education typically expresses output (the number of degrees produced) as a function of resources (grants and contracts, salaries and benefits, research expenditures, service expenditures…) and faculty instructional time allocation to teaching, research, and service. In functional form, this relationship can be expressed as:

$$Q = f\,(RES,\ ALLOC) \qquad (1)$$

where Q, RES, and ALLOC denote output, resources, and faculty instructional time allocation, respectively.

However, this specification ignores the fact that two production elements—students and faculty—enter the process upon considerable self-selection, especially among the more highly qualified of those elements. A model of production in higher education should reflect the broader perspective that quality of an academic department could influence the output. A control variable for quality of an academic department should, therefore, be introduced into the model; and in this study faculty compensation in an academic department is used as a proxy for the department's quality. Equation (1) can be expanded into the following:

$$Q = f\,(RES,\ ALLOC,\ QUAL) \qquad (2)$$

where Q, RES, ALLOC, and QUAL denote output, resources, faculty instructional time allocation, and quality of an academic department, respectively.

Because three levels of degree production (bachelor's, master's, and doctoral) are examined at the same time, they are modeled using seemingly unrelated regressions (SUR) to take into account the possibility that residuals of the regression equations may be correlated. Equation (2) can be rewritten as a system of three equations:

$$Q_B = f_B \text{ (RES, ALLOC, QUAL)} \quad (3)$$

$$Q_M = f_M \text{ (RES, ALLOC, QUAL)} \quad (4)$$

$$Q_D = f_D \text{ (RES, ALLOC, QUAL)} \quad (5)$$

where subscript B, M, and D denote bachelor's, master's, and doctoral levels, respectively.

It is hypothesized that the error terms of the three equations above are related because degree production processes at three degree production levels can be influenced by the same unobservable factors. In this case, using SUR to estimate the equations' coefficients will render more efficient estimates (Zellner, 1962). Put in other words, more estimation efficiency will be gained when using SUR to estimate two or more related regressions because of the combined information to be derived from them (Moon & Perron, 2008).

The basic SUR model assumes that for each individual observation *i* out of a total of *N* observations, there are *M* dependent variables $y_{i1}, y_{i2}, \ldots, y_{ij}, \ldots,$ and y_{iM} available, each with its own linear regression model:

$$y_{ij} = x_{ij}'\boldsymbol{\beta}_j + \varepsilon_{ij},$$

where $i = 1, \ldots, N$ and $j = 1, \ldots, M$. With the usual stacking of observations over *i*, this equation becomes

$$\boldsymbol{y}_j = \boldsymbol{X}_j\boldsymbol{\beta}_j + \boldsymbol{\varepsilon}_j,$$

where $\boldsymbol{y}_j$ and $\boldsymbol{\varepsilon}_j$ are (N x 1) vectors, $\boldsymbol{\beta}_j$ is a (K_j x 1) vector, and $\boldsymbol{X}_j$ is an (N x K_j) matrix, with K_j being the number of regressors for the j^{th} regression [$K_j = \dim(\boldsymbol{\beta}_j)$].

The standard conditions for the classical regression model are assumed to hold for each j^{th} regression; that is,

$$E(\mathbf{y}_j) = \mathbf{X}_j \boldsymbol{\beta}_j,$$

$$V(\mathbf{y}_j) = \sigma_{jj} \mathbf{I}_N,$$

where X_j is non-stochastic, rank(X_j) = K_j, and I_N is an (N x N) identity matrix,. Under these conditions and the additional condition of multi-normality of y_j, the usual inference theory is valid for the classical OLS estimator of $\boldsymbol{\beta}_j$, applied separately to each equation.

The SUR model, however, also permits non-zero covariance between the error terms ε_{ij} and ε_{ik} for a given observation *i* across equations *j* and *k*; that is,

$$Cov(\varepsilon_{ij}, \varepsilon_{ik}) = \sigma_{jk}$$

while assuming

$$Cov(\varepsilon_{ij}, \varepsilon_{i'k}) = 0$$

if $i \neq i'$. This can be expressed more compactly in the following matrix form:

$$C(\boldsymbol{\varepsilon}_j, \boldsymbol{\varepsilon}_k) = \sigma_{jk} \mathbf{I}_N.$$

This potential non-zero covariance across equations *j* and *k* allows for an improvement in efficiency of GLS relative to the classical OLS estimator of each $\boldsymbol{\beta}_j$ (Powell, 2006).

The 2005-2007 Delaware Cost Study provided panel data that spanned three years. Because the data set did not have identifiers, each university in the data set could not be followed up over time. (Actually, the University of Delaware's Office of Institutional Research and Planning requested that approval from each of the participant universities be obtained before the identifiers could be released to us. Fulfilling this requirement was beyond our reach.)

The above limitation means that methods commonly used to analyze panel data are not applicable here. Instead, another data structure is employed where the data are pooled cross-sectionally and year dummy variables are added to account for aggregate changes over time (Wooldridge, 2002, p. 128). The system of equations (3), (4), and (5) then become:

$$Q_B = f_B \text{ (RES, ALLOC, QUAL, TIME)} \tag{6}$$

$$Q_M = f_M \text{ (RES, ALLOC, QUAL, TIME)} \tag{7}$$

$$Q_D = f_D \text{ (RES, ALLOC, QUAL, TIME)} \tag{8}$$

where Q, RES, ALLOC, QUAL, and TIME denote output, resources, faculty instructional time allocation, quality of an academic department, and aggregate changes over years; and subscript B, M, and G denote bachelor's, master's, and doctoral levels, respectively.

In the field-level analysis, there are five categories (engineering, physical sciences, mathematics, life sciences, and social sciences) and three years (2005, 2006, and 2007). Social sciences and year 2005 are chosen to be the base categories in the model. At the departmental-level analysis in the two fields of engineering and physical sciences, only departments having at least six observations in three years (2005, 2006, and 2007) are taken into account. Those eight departments are, in engineering, chemical, civil, electrical, and mechanical, and, in the physical sciences, astronomy, chemistry, geosciences, and physics. Chemical engineering departments and year 2005 are chosen to be the base categories in the model.

All faculty instructional time allocation and financial data in the original data set are aggregate numbers for an academic department. To limit possible bias in favor of larger academic departments, per-FTE faculty averages were calculated for each department from the original aggregate numbers. For each faculty type in an academic department, per-FTE instructional time allocation were calculated by dividing the total annual student credit hours of that faculty type by the total FTE instructional faculty of that type. Per-FTE compensation was calculated by dividing the annual compensation budget of an academic department by its total FTE instructional faculty in three categories: tenured and tenure-track faculty, other regular faculty, and supplemental faculty. Per-FTE research expenditures were calculated by dividing the annual research expenditures of an academic department by its total FTE tenured/tenure-track faculty.

The system of equations (6), (7), and (8) can be expressed more specifically as follows:

Research question 1:

bach_degr = f_B (instr_fte_fac1, instr_fte_fac2, instr_fte_fac3, instr_fte_fac4,
perfte_und_lower_sch1, perfte_und_upper_sch1, perfte_und_ind_sch1,
perfte_und_lower_sch2, perfte_und_upper_sch2, perfte_und_ind_sch2,
perfte_und_lower_sch3, perfte_und_upper_sch3, perfte_und_ind_sch3,
perfte_und_lower_sch4, perfte_und_upper_sch4,
engr, phys, math, life,
perfte_comp_1000, perfte_sep_res_exp_1000,
year06 year07) (9)

mast_degr = f_M (instr_fte_fac1, instr_fte_fac2, instr_fte_fac3,
perfte_grad_sch1, perfte_grad_ind_sch1,
perfte_grad_sch2, perfte_grad_ind_sch2,
perfte_grad_sch3, perfte_grad_ind_sch3,
engr, phys, math, life,
perfte_comp_1000, perfte_sep_res_exp_1000,

year06 year07) (10)

doct_degr = f_D (instr_fte_fac1, instr_fte_fac2,

perfte_grad_sch1, perfte_grad_ind_sch1,

perfte_grad_sch2, perfte_grad_ind_sch2,

engr, phys, math, life,

perfte_comp_1000, perfte_sep_res_exp_1000,

year06 year07) (11)

Research question 2:

bach_degr = f_B (instr_fte_fac1, instr_fte_fac2, instr_fte_fac3, instr_fte_fac4,

perfte_und_lower_sch1, perfte_und_upper_sch1, perfte_und_ind_sch1,

perfte_und_lower_sch2, perfte_und_upper_sch2, perfte_und_ind_sch2,

perfte_und_lower_sch3, perfte_und_upper_sch3, perfte_und_ind_sch3,

perfte_und_lower_sch4, perfte_und_upper_sch4,

engr_civil, engr_elec, engr_mech,

phys_astro, phys_chem, phys_geosci phys_phys,

perfte_comp_1000, perfte_sep_res_exp_1000,

year06 year07) (12)

mast_degr = f_M (instr_fte_fac1, instr_fte_fac2, instr_fte_fac3,

perfte_grad_sch1, perfte_grad_ind_sch1,

perfte_grad_sch2, perfte_grad_ind_sch2,

perfte_grad_sch3, perfte_grad_ind_sch3,

engr_civil, engr_elec, engr_mech,

phys_astro, phys_chem, phys_geosci phys_phys,

perfte_comp_1000, perfte_sep_res_exp_1000,

year06 year07) (13)

doct_degr $= f_D$ (instr_fte_fac1, instr_fte_fac2,

perfte_grad_sch1, perfte_grad_ind_sch1,

perfte_grad_sch2, perfte_grad_ind_sch2,

engr_civil, engr_elec, engr_mech,

phys_astro, phys_chem, phys_geosci phys_phys,

perfte_comp_1000, perfte_sep_res_exp_1000,

year06 year07) (14)

A notional key to equations (9), (10), (11), (12), (13), and (14) is presented in Table 2 below.

Table 2. Summary of Variable Notation

Variable	Description
bach_degr	Number of bachelor's degrees produced
mast_degr	Number of master's degrees produced
doct_degr	Number of doctoral degrees produced
Tenured/tenure-track faculty	
instr_fte_fac1	Total FTE[(a)] instructional faculty
perfte_und_lower_sch1	Per-FTE undergraduate lower-division SCH[(b)]
perfte_und_upper_sch1	Per-FTE undergraduate upper-division SCH
perfte_und_ind_sch1	Per-FTE undergraduate individualized instruction SCH
perfte_grad_sch1	Per-FTE graduate SCH
perfte_grad_ind_sch1	Per-FTE graduate individualized instruction SCH
Other regular faculty	
instr_fte_fac2	Total FTE instructional faculty
perfte_und_lower_sch2	Per-FTE undergraduate lower-division SCH
perfte_und_upper_sch2	Per-FTE undergraduate upper-division SCH
perfte_und_ind_sch2	Per-FTE undergraduate individualized instruction SCH
perfte_grad_sch2	Per-FTE graduate SCH
perfte_grad_ind_sch2	Per-FTE graduate individualized instruction SCH

Supplemental faculty	
instr_fte_fac3	Total FTE instructional faculty
perfte_und_lower_sch3	Per-FTE undergraduate lower-division SCH
perfte_und_upper_sch3	Per-FTE undergraduate upper-division SCH
perfte_und_ind_sch3	Per-FTE undergraduate individualized instruction SCH
perfte_grad_sch3	Per-FTE graduate SCH
perfte_grad_ind_sch3	Per-FTE graduate individualized instruction SCH
(Credit-bearing) teaching assistants	
instr_fte_fac4	Total FTE instructional faculty
perfte_und_lower_sch4	Per-FTE undergraduate upper-division SCH
perfte_und_upper_sch4	Per-FTE undergraduate upper-division SCH
perfte_comp_1000	Per-FTE compensation (in thousand $)
perfte_sep_res_exp_1000	Per-FTE research expenditures (in thousand $)
Fields of science and engineering	
engr	Engineering
phys	Physical Sciences
math	Mathematical/Computer Sciences
life	Life Sciences

Departments in engineering and physical sciences	
engr_civil	Civil (Engineering)
engr_elec	Electrical (Engineering)
engr_mech	Mechanical (Engineering)
phys_astro	Astronomy (Physical Sciences)
phys_phys	Physics (Physical Sciences)
phys_chem	Chemistry (Physical Sciences)
phys_geosci	Geosciences (Physical Sciences)
year06	Year 2006
year07	Year 2007

(a): Full-time equivalent, (b): Student credit hours

CHAPTER 7

LIMITATIONS OF THE STUDY

The primary purpose of this study was to explore factors that influenced the degree production process within physical sciences and engineering departments at U.S. public universities. As was the case with most similar studies, there existed data limitations. Ideally, we would have preferred to have more financial data (for example, grants and contracts received, separately-budgeted service expenditures) and faculty time allocation data on research and service so that more detailed analysis was permissible and a broader picture of the degree production process could be obtained.

Regarding the data on the number of bachelor's, masters, and doctoral degrees produced, a potential limitation in the analysis arises from the fact that values of zero for particular units could be produced in two ways: via a an absence of students graduating with certain degree the unit offers, or via the degree simply not being offered by the unit. Making this distinction was impossible using the available data. That the data set contained no information on faculty ranks was another limitation of the study as there were supposed to be significant differences among them.

Another limitation of the study was that it focused on the *teaching* activity of universities. Research and service were given less weight. Teaching was the focus because the study's focus was how resources and faculty instructional time allocation affected the degree production process. This did not mean the significance of research was ignored. In fact, research activities were taken into account as a predictor in the model—with separately-budgeted research expenditures being the proxy—in order to help explain the degree production process. Service-related activities of faculty were not reflected in the models because of considerable missing data.

This study was limited to public universities. It could be argued that the degree production function of private universities is different from that of public universities due to differences in funding structures, operational priorities, and obligations to community. Unfortunately, data for private universities were not available.

CHAPTER 8

FINDINGS AND DISCUSSION

Table 3 below contains the descriptive data for the variables used in the models at the field level. The data revealed interesting information about the structure and roles of different faculty types within a department. On average and across all five fields of science and engineering, tenured/tenure-track faculty in an academic department still outnumbered other faculty types (other regular faculty, supplemental faculty, and teaching assistants). The mean number of tenured/tenure-track faculty in a department was 16.13; whereas for other regular faculty, supplemental faculty, and teaching assistants, the figures were 1.86, 3.48, and 3.16, respectively.

Table 3. Descriptive Statistics of the Variables in the Models at the Field Level

Variable	Obs	Mean	SD	Min	Max
Bachelor's degrees produced	373	65.46	70.2364	0.00	397.00
Master's degrees produced	373	18.50	19.9334	0.00	111.00
Doctoral degrees produced	373	7.32	6.4959	0.00	39.00
Instructional FTE[(a)] faculty (Tenured/Tenure-track)	373	16.13	9.9218	0.00	56.26
Instructional FTE faculty (Other regular)	373	1.86	3.8616	0.00	39.46
Instructional FTE faculty (Supplemental)	373	3.48	4.9923	0.00	35.23
Instructional FTE faculty (Teaching assistants)	373	3.16	5.6616	0.00	37.75
Per-FTE undergraduate lower-division SCH[(b)] (Tenured/Tenure-track)	373	172.52	207.3812	0.00	1728.48
Per-FTE undergraduate upper-division SCH (Tenured/Tenure-track)	373	170.33	131.1747	0.00	799.29
Per-FTE undergraduate individual-instruction SCH (Tenured/Tenure-track)	373	5.61	8.0768	0.00	85.04
Per-FTE undergraduate lower-division SCH (Other regular)	373	406.58	868.6186	0.00	5472.60
Per-FTE undergraduate upper-division SCH (Other regular)	373	178.60	337.6011	0.00	1929.08
Per-FTE undergraduate individual-instruction SCH (Other regular)	373	3.66	22.5620	0.00	408.65
Per-FTE undergraduate lower-division SCH (Supplemental)	373	319.30	642.0680	0.00	4627.59

Variable	Obs	Mean	SD	Min	Max
Per-FTE undergraduate upper-division SCH (Supplemental)	373	181.10	294.4791	0.00	1927.56
Per-FTE undergraduate individual-instruction SCH (Supplemental)	373	5.70	19.1472	0.00	282.38
Per-FTE undergraduate lower-division SCH (Teaching assistants)	373	305.24	566.7190	0.00	4028.66
Per-FTE undergraduate upper-division SCH (Teaching assistants)	373	222.05	497.1054	0.00	3688.13
Per-FTE faculty compensation (unit: $1,000)	373	137.21	34.9371	40.43	397.76
Per-FTE faculty research expenditures (unit: $1,000)	373	218.41	331.6226	0.00	3789.94
Per-FTE graduate SCH (Tenured/Tenure-track)	373	60.37	69.8438	0.00	407.75
Per-FTE graduate individual-instruction SCH (Tenured/Tenure-track)	373	34.45	34.5269	0.00	204.63
Per-FTE graduate SCH (Other regular)	373	39.77	113.1608	0.00	1080.47
Per-FTE graduate individual-instruction SCH (Other regular)	373	3.24	9.1343	0.00	82.30
Per-FTE graduate SCH (Supplemental)	373	31.31	94.0186	0.00	736.34
Per-FTE graduate individual-instruction SCH (Supplemental)	373	12.61	59.9982	0.00	1033.63

(a): Full-time equivalent, (b): Student credit hours

Although numbers of tenured/tenure-track faculty were still the biggest component in a department's faculty composition, the per-FTE undergraduate student credit hours produced by this faculty type were the smallest. The descending order of per-FTE undergraduate (lower-division and upper-division) student credit hours produced by different faculty types were as follows: other regular faculty (585.18), teaching assistants (527.29), supplemental faculty (500.40), and tenured/tenure-track faculty (342.85). Data on per-FTE undergraduate individualized instruction student credit hours, however, showed a different trend, with supplemental faculty and tenured/tenure-track faculty accounting for the most per-FTE undergraduate individualized instruction student credit hours (5.70 and 5.61, respectively). Other regular faculty accounted for only 3.66 per-FTE undergraduate individualized instruction student credit hours.

The per-FTE graduate student credit hours displayed a different trend. Although the data set did not separate graduate student credit hours into master's student credit hours and doctoral student credit hours, the general trend was that tenured/tenure-track faculty accounted for the most per-FTE graduate student credit hours (60.37), followed by other regular faculty (39.77) and supplemental faculty (31.31). Tenured/tenure-track faculty also accounted for the most per-FTE graduate student individualized instruction credit hours (34.45), with supplemental faculty and other regular faculty following behind (12.61 and 3.24, respectively). Apparently tenured/tenure-track faculty probably assumed the biggest role in teaching doctoral students, and other regular and supplemental faculty took up the major part in teaching master's students.

The mean annual compensation for a faculty member (across three categories: tenured/tenure-track, other regular, and supplemental faculty) was $137,210, and the per-FTE research expenditures for tenured/tenure-track faculty were $218,410. As can be seen from table 3, the data displayed significant variability as reflected in standard deviations, minimum values, and maximum values. This suggested that there were measurable differences among five fields of science and engineering. These differences are examined in detail below.

Table 4. Field-Level Degree Production, by Three Degree Levels (Bachelor's, Master's, and Doctoral), as Functions of Departmental Production Elements

Equation	Observations	Parameters	RMSE	Adjusted R-squared	Chi-squared	P-value
(1) Bachelor's degrees produced	373	23	42.5938	0.6067	642.72	0.000
(2) Master's degrees produced	373	17	14.6830	0.4299	315.29	0.000
(3) Doctoral degrees produced	373	14	4.2061	0.5636	514.11	0.000

Variable	(1) Bachelor's degrees produced	(2) Master's degrees produced	(3) Doctoral degrees produced
Instructional FTE[(a)] faculty (Tenured/Tenure-track)	3.7766*** (0.0000)	0.5819*** (0.0000)	0.4482*** (0.0000)
Instructional FTE faculty (Other regular)	1.5312** (0.0239)	0.5328** (0.0138)	-0.2046*** (0.0007)
Instructional FTE faculty (Supplemental)	0.2745 (0.6509)	0.0450 (0.8064)	--

Variable	Bachelor's degrees produced	Master's degrees produced	Doctoral degrees produced
Instructional FTE faculty (Teaching assistants)	-0.4098 (0.4869)	--	--
Per-FTE undergraduate lower-division SCH[(b)] (Tenured/Tenure-track)	0.0712*** (0.0000)	--	--
Per-FTE undergraduate upper-division SCH (Tenured/Tenure-track)	0.0917*** (0.0000)	--	--
Per-FTE undergraduate individual-instruction SCH (Tenured/Tenure-track)	0.2807 (0.3983)	--	--
Per-FTE undergraduate lower-division SCH (Other regular)	0.0064** (0.0249)	--	--
Per-FTE undergraduate upper-division SCH (Other regular)	0.0247*** (0.0012)	--	--
Per-FTE undergraduate individual-instruction SCH (Other regular)	0.0818 (0.4175)	--	--
Per-FTE undergraduate lower-division SCH (Supplemental)	0.0058 (0.1143)	--	--
Per-FTE undergraduate upper-division SCH (Supplemental)	0.0464*** (0.0000)	--	--

Variable	Bachelor's degrees produced	Master's degrees produced	Doctoral degrees produced
Per-FTE undergraduate individual-instruction SCH (Supplemental)	0.0343 (0.7865)	--	--
Per-FTE undergraduate lower-division SCH (Teaching assistants)	0.0082* (0.0681)	--	--
Per-FTE undergraduate upper-division SCH (Teaching assistants)	0.0243*** (0.0000)	--	--
Engineering	-6.9354 (0.4007)	26.7029*** (0.0000)	1.4223* (0.0512)
Physical Sciences	-80.1870*** (0.0000)	-1.9631 (0.4843)	2.0828*** (0.0095)
Mathematical/Computer Sciences	-54.8396*** (0.0000)	4.9408 (0.1012)	-1.9280** (0.0244)
Life Sciences	3.0040 (0.6677)	4.4613* (0.0576)	1.8784*** (0.0031)
Per-FTE faculty compensation (unit: $1,000)	0.2217*** (0.0021)	0.0398* (0.0945)	0.0474*** (0.0000)
Per-FTE faculty research expenditures (unit: $1,000)	0.0040 (0.5864)	-0.0005 (0.8300)	0.0024*** (0.0011)

Variable	Bachelor's degrees produced	Master's degrees produced	Doctoral degrees produced
Year 2006	-2.8493 (0.5959)	-1.5449 (0.4023)	-0.9530* (0.0713)
Year 2007	-2.4973 (0.6679)	1.5100 (0.4521)	-0.1047 (0.8551)
Per-FTE graduate SCH (Tenured/Tenure-track)	--	0.0923*** (0.0000)	0.0043 (0.3272)
Per-FTE graduate individual-instruction SCH (Tenured/Tenure-track)	--	0.0089 (0.7347)	0.0262*** (0.0004)
Per-FTE graduate SCH (Other regular)	--	0.0083 (0.3940)	0.0017 (0.5410)
Per-FTE graduate individual-instruction SCH (Other regular)	--	0.0392 (0.6584)	-0.0222 (0.3759)
Per-FTE graduate SCH (Supplemental)	--	0.0316*** (0.0007)	--
Per-FTE graduate individual-instruction SCH (Supplemental)	--	-0.0103 (0.4236)	--

Variable	Bachelor's degrees produced	Master's degrees produced	Doctoral degrees produced
Constant	-66.4949*** (0.0000)	-9.9083*** (0.0069)	-8.1836*** (0.0000)

(a): Full-time equivalent, (b): Student credit hours

P-values in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 4 contains the regression outputs for the number of bachelor's, master's, and doctoral degrees produced as a function of faculty time allocation, faculty compensation, and research expenditures. As displayed by the R-squared values, the independent variables in the models explained 60.67%, 42.99%, and 56.36% the total variability in the production of bachelor's, master's, and doctoral degrees, respectively.

In the production of bachelor's degrees, the numbers of tenured/tenure-track faculty and other regular faculty were positively and significantly associated with the production process. On average an increase of one FTE tenured/tenure-track faculty member was associated with an increase of four (3.7766) units in the number of bachelor's degrees produced, and an increase of one other regular faculty member led to an increase of two (1.5312) bachelor's degrees produced. This finding underlined the importance of the number of tenured/tenure-track and other regular faculty in the production of bachelor's degrees. The numbers of supplemental faculty and teaching assistants did not have any significant relationships with the degree production process; however, their per-FTE student credit hours did have a significant role in the number of degrees produced, as presented below.

Per-FTE student credit hours by tenured/tenured-track and other regular faculty at the lower-division level were positively correlated with the number of bachelor's degrees produced. Per-FTE student credit hours by supplemental faculty did not have any significant relationship with the production of bachelor's degrees whereas per-FTE student credit hours by teaching assistants marginally did (at the 10% confidence interval). On average a one-unit increase in per-FTE student credit hours by tenured/tenure-track faculty, other regular faculty, and teaching assistants was associated with an increase of 0.0712, 0.0064, and 0.0082 units, respectively, in the number of bachelor's degrees produced.

The findings on per-FTE student credit hours by different faculty types at the upper-division level showed a somewhat different pattern, with per-FTE student credit hours by all four faculty types (tenured/tenure-track faculty, other regular faculty, supplemental faculty, and teaching assistants) having significant relationships with the number of bachelor's degrees produced. As can be seen from table 4 above, the coefficients of per-FTE upper-division student credit hours by those four faculty types were all positively significant: A one-unit increase in per-FTE upper-division student credit hours by tenured/tenure-track faculty, other regular faculty, supplemental faculty, and teaching assistants was associated with an increase of 0.0917, 0.0247, 0.0464, and 0.0243 units, respectively, in the number of bachelor's degrees produced.

Table 4 also reveals that per-FTE undergraduate individualized instruction student credit hours by three faculty types (tenured/tenure-track faculty, other regular faculty, and supplemental faculty) did not have significant relationships with the number of bachelor's degrees produced. This, perhaps, could be explained as follows: Per-FTE undergraduate individualized instruction student credit hours only mattered in the production of graduate degrees, where students had to conduct their own research as part of the required curriculum and therefore needed to interact more with faculty individually.

All above figures related to per-FTE student credit hours by different faculty types at the lower- and upper-division levels revealed that tenured-tenure-track faculty still played the vital role in producing bachelor's degrees. A one-unit increase in per-FTE student credit hours produced by tenured/tenure-track faculty at the lower- and upper-division levels was associated with an increase of 0.0712 and 0.0917 units, respectively, in the number of bachelor's degrees produced; and these two figures were higher than those of other regular faculty (0.0064 and 0.0247), supplemental faculty (0.0058 and 0.0464), and teaching assistants (0.0082 and 0.0243).

These findings also revealed that although tenured/tenure-track faculty still assumed the most important role in the production of undergraduate degrees, other faculty types (other regular faculty, supplemental faculty, and teaching assistants) also contributed significantly to the production process.

Per-FTE faculty compensation was positively associated with the number of bachelor's degrees produced. On average an increase of $1,000 in per-FTE faculty compensation was associated with an increase of 0.2217 units in the number of bachelor's degrees produced. Perhaps larger universities paid their faculty more, and they, of course, admitted and graduated more students, too. Table 4 above also reveals that per-FTE separately-budgeted research expenditures of faculty did not have any significant relationship with the number of undergraduate degrees produced. Similarly, the coefficients of the year dummy variables were not significant either. Perhaps only three years of data (2005-2007) was not enough to detect any trends in the number of degrees produced.

The dummy variable coefficients of the four fields of science and engineering (engineering, physical sciences, mathematical/computer sciences, and life sciences, with social sciences being the base category) revealed several interesting findings. The regression output in table 4 shows that there was no significant difference in the numbers of bachelor's degrees produced among engineering, life sciences, and social sciences; whereas physical sciences and mathematical/computer sciences produced fewer bachelor's degrees than social sciences. On average physical sciences and mathematical/computer sciences produced 80.1870 and 54.8396 degrees fewer, respectively, than social sciences.

The above findings could be explained as follows: first, more students chose to study in the social sciences, probably in part due to the fact that the other curricula were more demanding, but probably also simply because more students preferred to work in areas where there was more "human contact." Second, physical sciences and mathematical/computer sciences produced fewer bachelor's degrees because employment opportunities were more limited, the curricula more demanding, and jobs in these fields more often required graduate study (master's or doctoral programs). The fact that mathematical/computer sciences and physical sciences produced fewer bachelor's degrees could also be explained by a large amount of service teaching (fundamental courses in mathematics, physics, or chemistry) conducted by departments in these two fields to other departments on campus.

The production process of master's degrees revealed a different pattern from that of bachelor's degree production. Table 4 shows that at the master's degree level, only the numbers of the tenured/tenure-track faculty and other regular faculty had positive and significant relationship with the number of master's degrees produced. On average a one-unit increase in instructional FTE tenured/tenure-track faculty and other regular faculty was associated with an increase of 0.5819 and 0.5328 units, respectively, in the number of master's degrees. Apparently, other regular faculty were nearly as much involved as tenured/tenure-track faculty in the production of master's degrees, as reflected by the coefficients. (At the bachelor's degree level, the number of degrees produced by a one-unit increase in the instructional FTE tenured/tenure-track faculty was more than twice as many as that produced by a one-unit increase in the instructional FTE other regular faculty.) The number of FTE supplemental faculty did not have any significant relationship with the number of master's degrees produced;

however, their per-FTE graduate student credit hours did have a significant association with the production of master’s degrees, as explained below.

The important role of tenured/tenure-track faculty in the production of master’s degree holders was underlined by the significant relationship between per-FTE graduate student credit hours by tenured/tenure-track faculty and the number of master’s degree produced. On average an increase of one unit in per-FTE graduate student credit hours by tenured/tenure-track faculty was associated with an increase of 0.0923 units in the number of master’s degrees produced. This was the largest increase as compared with the effects of per-FTE graduate student credit hours by other regular faculty or supplemental faculty. As can be seen from table 4, a one-unit increase in per-FTE graduate student credit hours by other regular faculty did not have a significant relationship with the production of master’s degrees, and a one-unit increase in per-FTE graduate student credit hours by supplemental faculty led to an increase of only 0.0316 units in the number of master’s degrees produced.

Per-FTE graduate individualized instruction student credit hours by all faculty types (tenured/tenure-track, other regular, and supplemental faculty), which were mostly used for students who were writing up their theses, were not significantly associated with the number of master’s degrees produced. Perhaps graduate individualized instruction was seldom used, comparatively, at this production level as many master’s programs did not require a thesis as one of the requirements to graduate. The findings also revealed that per-FTE faculty compensation was positively and significantly associated with the number of master’s degrees produced (at the 10% confidence interval). Perhaps larger universities paid their faculty more, and they, of course, admitted and graduated more students. The coefficients of per-FTE faculty separately-budgeted research expenditures and year dummy variables did not have any significant relationship with the number of master's degrees produced.

The dummy variable coefficients of the four fields of science and engineering (engineering, physical sciences, mathematical/computer sciences, and life sciences, with social sciences being the base category) at the master's degree level revealed several interesting findings, which were different from those in the production of bachelor's degrees. As can be seen from table 4, the coefficients of engineering and life sciences were significantly positive at the respective 1% and 10% confidence intervals. On average these two fields produced 26.7029 and 4.4613 degrees more than social sciences, respectively. The numbers of master's degrees produced by physical sciences and mathematical/computer sciences were not significantly different from that by social sciences.

This finding could be explained by stronger market demand for engineers at the master's degree level. There were more employment opportunities for master's degree holders in engineering, and many of them could get a job without having to complete doctoral study. In fact, in engineering the master's degree is often the "terminal degree" from a labor market perspective. The situation was different for master's students in physical sciences, mathematical/computer sciences, or social sciences, where they would usually find that employment opportunities were more limited and where the doctoral degree more commonly is the "terminal degree." Bachelor's degree holders in these fields would, therefore, be more likely to pursue doctoral study.

The production of doctoral degrees at the field level revealed a different pattern from those of the production of bachelor's and master's degrees. The number of FTE tenured/tenure-track faculty was significantly and positively associated with the number of doctoral degrees produced. On average a one-unit increase in the number of FTE tenured/tenure-track faculty led to an increase of 0.4482 units in the number of doctoral degrees produced. This finding was expected because tenured/tenure-track faculty played the most important role in producing doctoral degree holders.

The number of FTE other regular faculty was also significantly associated with the number of doctoral degrees produced, but negatively. This was not a surprising finding if viewed in line with the findings at the bachelor's and master's levels where the number of FTE other regular faculty was positively and significantly associated with the numbers of bachelor's and master's degrees produced. In aggregation, the negative relationship between the number of FTE other regular faculty and the production of doctoral degrees together with the positive relationship between the number of FTE other regular faculty and the production of bachelor's and master's degrees meant that teaching responsibilities of other regular faculty were primarily at the bachelor's and master's levels.

Table 4 also reveals interesting findings about the relationship between per-FTE student credit hours by faculty type and the number of doctoral degrees produced. The per-FTE graduate student credit hours by tenured/tenure-track faculty were not significantly associated with the production of doctoral degrees; however, the per-FTE graduate individual instruction student credit hours by tenured/tenure-track faculty had a positive and significant relationship with the number of doctoral degrees produced. On average an increase of one unit in per-FTE graduate individual instruction student credit hours by tenured/tenure-track faculty was associated with an increase of 0.0262 units in the number of doctoral degrees produced. This finding underlined the fact that unlike the degree production at the bachelor's and master's levels, the interaction between faculty and doctoral students played a vital role in the production of doctoral degrees. The per-FTE graduate student credit hours and graduate individual instruction credit hours by other regular faculty did not have any significant relationship with the doctoral degree production. This was consistent with a previous finding that teaching responsibilities of other regular faculty were primarily at the bachelor's and master's levels.

The coefficients of faculty's per-FTE compensation and separately-budgeted research expenditures were both positively significant. On average an increase of $1,000 in per-FTE faculty compensation was associated with an increase of 0.0474 units in the number of doctoral degrees produced. Probably universities that paid their faculty more were those that admitted and graduated more doctoral students. As far as the per-FTE separately-budgeted research expenditures were concerned, each $1,000 increase in research expenditures was associated with an increase of 0.0024 units in the number of doctoral degrees produced. This finding could be explained by the positive relationship between research funds of faculty and the number of doctoral students they were able to take in. As faculty gained more research funds, they could accept more doctoral students into their programs and therefore would produce relatively more doctoral degree holders. The dummy variable coefficient for year 2007 was not significant, and that of year 2006 was marginally significant at the 10% confidence level.

Among the coefficients of the four dummy variables representing engineering, physical sciences, mathematical/computer sciences, and life sciences (social sciences being the base category), those of physical sciences and life sciences were positively significant, and that of mathematical/computer sciences negatively significant. That meant all other things being equal, physical sciences and life sciences each produced 2.0828 and 1.8784 doctoral degrees more than social sciences, respectively, whereas mathematical/computer sciences produced 1.928 doctoral degrees fewer than social sciences. The coefficient of the dummy variable for engineering was positively significant at the 10% confidence interval. On average, engineering produced 1.4223 doctoral degrees more than social sciences. All of this, again, could be explained by the fact that different fields had different degree requirements. To be more specifically, for most employment opportunities one needs a doctoral degree in physical sciences or life sciences but only a master's or bachelor's degree in engineering.

With the analysis at the field level as a backdrop, this study continued to examine the production of bachelor's master's, and doctoral degrees at the departmental level in two fields engineering and physical sciences. Table 5 below shows descriptive information for the variables used in the models.

Table 5. Descriptive Statistics of the Variables in the Models at the Departmental Level in Engineering and Physical Sciences

Variable	Obs	Mean	SD	Min	Max
Bachelor's degrees produced	73	53.11	43.4932	1.00	159.00
Master's degrees produced	73	24.63	25.8019	3.00	111.00
Doctoral degrees produced	73	13.79	9.0691	2.00	39.00
Instructional FTE[(a)] faculty (Tenured/Tenure-track)	73	24.99	8.7689	8.50	40.67
Instructional FTE faculty (Other regular)	73	1.30	1.3004	0.00	4.33
Instructional FTE faculty (Supplemental)	73	4.41	5.3497	0.00	31.00
Instructional FTE faculty (Teaching assistants)	73	4.28	7.6928	0.00	37.75
Per-FTE undergraduate lower-division SCH[(b)] (Tenured/Tenure-track)	73	194.84	140.1175	8.22	545.22
Per-FTE undergraduate upper-division SCH (Tenured/Tenure-track)	73	118.99	68.4049	15.87	294.44
Per-FTE undergraduate individual-instruction SCH (Tenured/Tenure-track)	73	3.29	3.4232	0.00	14.13
Per-FTE undergraduate lower-division SCH (Other regular)	73	601.24	866.9511	0.00	3,340.13
Per-FTE undergraduate upper-division SCH (Other regular)	73	157.24	295.6968	0.00	1,685.24
Per-FTE undergraduate individual-instruction SCH (Other regular)	73	1.33	3.1982	0.00	18.90
Per-FTE undergraduate lower-division SCH (Supplemental)	73	385.93	661.6912	0.00	3,269.61

Variable	Obs	Mean	SD	Min	Max
Per-FTE undergraduate upper-division SCH (Supplemental)	73	161.15	221.9655	0.00	1,113.73
Per-FTE undergraduate individual-instruction SCH (Supplemental)	73	4.84	9.0321	0.00	47.01
Per-FTE undergraduate lower-division SCH (Teaching assistants)	73	160.91	196.8022	0.00	663.61
Per-FTE undergraduate upper-division SCH (Teaching assistants)	73	142.04	276.8160	0.00	1,479.14
Per-FTE faculty compensation (unit: $1,000)	73	147.58	27.2022	84.98	224.99
Per-FTE faculty research expenditures (unit: $1,000)	73	329.80	369.2061	0.00	3,049.84
Per-FTE graduate SCH (Tenured/Tenure-track)	73	31.62	18.3342	5.73	97.13
Per-FTE graduate individual-instruction SCH (Tenured/Tenure-track)	73	36.55	28.7404	9.33	148.12
Per-FTE graduate SCH (Other regular)	73	15.99	50.7848	0.00	398.53
Per-FTE graduate individual-instruction SCH (Other regular)	73	1.46	4.0814	0.00	24.31
Per-FTE graduate SCH (Supplemental)	73	10.51	17.8542	0.00	86.73
Per-FTE graduate individual-instruction SCH (Supplemental)	73	12.75	17.5473	0.00	72.54

(a): Full-time equivalent, (b): Student credit hours

The data revealed preliminary information about the structure and roles of different faculty types within a department in engineering and physical sciences. On average and across the departments in the study—civil engineering, electrical engineering, mechanical engineering, chemical engineering, astronomy, chemistry, geosciences, and physics, tenured/tenure-track faculty in an academic department still outnumbered other faculty types (other regular faculty, supplemental faculty, and teaching assistants). The mean number of tenured/tenure-track faculty in the departments was 24.99; whereas for other regular faculty, supplemental faculty, and teaching assistants, the figures were 1.30, 4.41, and 4.28, respectively.

In these engineering and physical science departments, although numbers of tenured/tenure-track faculty were still the biggest component in a department's faculty composition, the per-FTE undergraduate student credit hours produced by this faculty type were among the smallest. The descending order of per-FTE undergraduate (lower-division and upper-division) student credit hours produced by different faculty types were as follows: other regular faculty (758.48) supplemental faculty (547.08), tenured/tenure-track faculty (313.83), and teaching assistants (302.95). It can also be seen that contrasting with data of the five fields of science and engineering where the average per-FTE undergraduate student credit hours carried out by teaching assistants were among the highest, the average per-FTE undergraduate student credit hours carried out by teaching assistants in engineering and physical science departments were among the lowest. Perhaps at the field level, the average per-FTE undergraduate student credit hours were very strongly influenced by social sciences, where there was the largest number of undergraduate enrollments. In engineering and physical science departments, relatively, the number of undergraduate students was much smaller. Additionally, these students normally took fundamental courses (mathematics, physics, chemistry, and writing) in arts and sciences colleges, which further deflated the average per-FTE undergraduate student credit hours carried out by teaching assistants in engineering and physical science departments (Cross and Goldenberg, 2009, p. 27). Data on per-FTE undergraduate individualized instruction student credit hours, however, showed a slightly different trend, with supplemental faculty and tenured/tenure-track faculty accounting for the most per-FTE undergraduate individualized instruction student credit hours (4.84 and 3.29, respectively). Other regular faculty accounted for only 1.33 per-FTE undergraduate individualized instruction student credit hours.

The per-FTE graduate student credit hours displayed a different trend. Although the data set did not separate graduate student credit hours into master's doctoral student levels, the general trend was that tenured/tenure-track faculty accounted for the most per-FTE graduate student credit hours (31.62), followed by other regular faculty (15.99) and supplemental faculty (10.51). Tenured/tenure-track faculty also accounted for the most per-FTE graduate student individualized instruction credit hours (36.55), with supplemental faculty and other regular faculty following behind (12.75 and 1.46, respectively). Perhaps tenured/tenure-track faculty probably assumed the biggest role in teaching doctoral students, and other regular and supplemental faculty took up the major part in teaching master's students. Also, usually doctoral dissertation and research credit hours are classified as individualized instruction.

The mean annual compensation for a faculty member (across three categories: tenured/tenure-track, other regular, and supplemental faculty) was $147,580, and the per-FTE research expenditures for tenured/tenure-track faculty were $329,800. As can be seen from table 5, the data displayed significant variability as reflected in standard deviations, minimum values, and maximum values. This suggested that there were substantial differences among academic departments in engineering and physical sciences. These differences are examined in detail below.

Table 6. Departmental-Level Degree Production in Engineering and Physical Sciences, by Three Degree Levels (Bachelor's, Master's, and Doctoral), as Functions of Departmental Production Elements

Equation	Observations	Parameters	RMSE	Adjusted R-squared	Chi-squared	P-value
(1) Bachelor's degrees produced	73	26	11.6686	0.8857	997.99	0.0000
(2) Master's degrees produced	73	20	7.2652	0.8892	841.27	0.0000
(3) Doctoral degrees produced	73	17	3.0939	0.8455	552.39	0.0000

Variable	(1) Bachelor's degrees produced	(2) Master's degrees produced	(3) Doctoral degrees produced
Instructional FTE[(a)] faculty (Tenured/Tenure-track)	1.2686*** (0.0002)	0.7995*** (0.0013)	0.7734*** (0.0000)
Instructional FTE faculty (Other regular)	1.7207 (0.4713)	2.7344* (0.0653)	-1.4614*** (0.0012)
Instructional FTE faculty (Supplemental)	-0.1971 (0.6711)	0.3421 (0.1872)	--

Variable	(1) Bachelor's degrees produced	(2) Master's degrees produced	(3) Doctoral degrees produced
Instructional FTE faculty (Teaching assistants)	-0.4129 (0.2009)	--	--
Per-FTE undergraduate lower-division SCH[(b)] (Tenured/Tenure-track)	-0.0323* (0.0784)	--	--
Per-FTE undergraduate upper-division SCH (Tenured/Tenure-track)	-0.0458 (0.2023)	--	--
Per-FTE undergraduate individual-instruction SCH (Tenured/Tenure-track)	1.0886 (0.1403)	--	--
Per-FTE undergraduate lower-division SCH (Other regular)	0.0013 (0.5320)	--	--
Per-FTE undergraduate upper-division SCH (Other regular)	-0.0018 (0.7639)	--	--
Per-FTE undergraduate individual-instruction SCH (Other regular)	-0.8099 (0.1894)	--	--
Per-FTE undergraduate lower-division SCH (Supplemental)	-0.0025 (0.4628)	--	--
Per-FTE undergraduate upper-division SCH (Supplemental)	0.0029 (0.7234)	--	--

Variable	(1) Bachelor's degrees produced	(2) Master's degrees produced	(3) Doctoral degrees produced
Per-FTE undergraduate individual-instruction SCH (Supplemental)	0.8026*** (0.0002)	--	--
Per-FTE undergraduate lower-division SCH (Teaching assistants)	0.0007 (0.9492)	--	--
Per-FTE undergraduate upper-division SCH (Teaching assistants)	0.0106 (0.2142)	--	--
Civil Engineering	12.9789 (0.1026)	30.4969*** (0.0000)	-4.2687** (0.0344)
Electrical Engineering	48.8705*** (0.0000)	66.3991*** (0.0000)	-8.8171*** (0.0002)
Mechanical engineering	62.8401*** (0.0000)	25.8510*** (0.0000)	-8.0003*** (0.0000)
Astronomy	-32.1684*** (0.0025)	7.0203 (0.2074)	-7.0931*** (0.0020)
Chemistry	-0.1128 (0.9913)	-18.3117** (0.0230)	4.3676 (0.1466)
Geosciences	-27.2821*** (0.0025)	4.6361 (0.3950)	-9.0037*** (0.0000)

Variable	(1) Bachelor's degrees produced	(2) Master's degrees produced	(3) Doctoral degrees produced
Physics	-37.8097*** (0.0002)	-9.4882* (0.0648)	-11.4243*** (0.0000)
Per-FTE faculty compensation (unit: $1,000)	-0.0371 (0.7276)	0.1297 (0.1336)	0.0421 (0.2027)
Per-FTE faculty research expenditures (unit: $1,000)	0.0021 (0.6543)	-0.0018 (0.5472)	0.0007 (0.5346)
Year 2006	-5.3801 (0.1168)	-0.3219 (0.8862)	-1.7221* (0.0672)
Year 2007	-2.8121 (0.4805)	0.2250 (0.9288)	-0.3217 (0.7625)
Per-FTE graduate SCH (Tenured/Tenure-track)	--	0.0097 (0.8982)	0.0013 (0.9650)
Per-FTE graduate individual-instruction SCH (Tenured/Tenure-track)	--	0.1646*** (0.0019)	-0.0528** (0.0145)
Per-FTE graduate SCH (Other regular)	--	-0.0230 (0.3259)	-0.0091 (0.3338)
Per-FTE graduate individual-instruction SCH (Other regular)	--	0.4849* (0.0955)	0.1147 (0.3247)

Variable	(1) Bachelor's degrees produced	(2) Master's degrees produced	(3) Doctoral degrees produced
Per-FTE graduate SCH (Supplemental)	--	0.0203 (0.7209)	--
Per-FTE graduate individual-instruction SCH (Supplemental)	--	-0.0685 (0.2604)	--
Constant	36.9119* (0.0514)	-32.8563* (0.0634)	-1.9850 (0.7736)

(a): Full-time equivalent, (b): Student credit hours

P-values in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 6 contains the regression outputs for the number of bachelor's, master's, and doctoral degrees produced as a function of faculty time allocation, faculty compensation, and research expenditures. As displayed by the R-squared values, the independent variables in the models explained 88.57%, 88.92%, and 84.55% the total variability in the production of bachelor's, master's, and doctoral degrees, respectively.

Table 6 also shows that the number of tenured/tenure-track faculty was positively and significantly associated with the number of bachelor's degrees produced by academic departments in engineering and physical sciences. On average a one-unit increase in the number of tenured/tenure-track FTE faculty was associated with an increase of 1.2686 units in the production of bachelor's degrees. The per-FTE undergraduate lower-division student credit hours carried out by tenured/tenure-track faculty were, however, negatively and significantly associated with the production of bachelor's degrees. On average a one-unit increase in these lower-division student credit hours by tenured/tenure-track faculty led to a decrease of 0.0323 units in the number of bachelor's degrees produced. The numbers of other regular, supplemental faculty, and teaching assistants did not have a significant relationship with the degree production at this award level. Similarly, the per-FTE undergraduate lower-division, upper-division, and individualized instruction student credit hours by these faculty types did not have significant relationships with the number of bachelor's degrees produced, except for the individualized instruction student credit hours by supplemental faculty. (On average a one unit increase in the per-FTE undergraduate individualized instruction student credit hours by supplemental faculty was associated with an increase of 0.8026 units in the number of bachelor's degrees produced.).

These findings suggested that although still playing an important role in the production of bachelor's degrees, tenured/tenure-track faculty were shifting their focus to the production of graduate degrees, as will be shown in subsequent analysis of the master's and doctoral levels. With tenured/tenure-track faculty focusing more on the graduate degree production, the employment of other types of faculty could have assumed an increasingly important role in producing bachelor's degrees, at least in engineering. Cross and Goldenberg (2009, p. 27) lent additional insights into these matters and pointed out several reasons the growing number of non-tenure-track faculty was till understated. First, undergraduate students in engineering still took prerequisite courses (mathematics, physics, chemistry, and writing) in arts and sciences colleges, which made the greatest use of non-tenure-track faculty. In short engineering departments indirectly used non-tenure-track faculty assigned elsewhere. Second, the relative growth in research funds in engineering led to an increased number of research scientists who were rarely recorded as non-tenure-track faculty and who often were assigned relatively lighter teaching loads. Table 6 also revealed that per-FTE faculty compensation and per-FTE separately-budgeted faculty research expenditures did not have significant relationships with the number of bachelor's degrees produced. Similarly, the year dummy variables were not significantly associated with the degree production at this bachelor's level due, perhaps, to the short time period of the study (3 years, from 2005 to 2007).

The dummy variable coefficients of academic departments in engineering (civil, electrical, mechanical, and chemical engineering--the base category) and physical sciences (astronomy, chemistry, geosciences, and physics) revealed findings that were generally consistent with those at the field level; that is, academic departments in engineering produced more bachelor's degree holders than their counterparts in physical sciences. As can be seen from table 6 above, electrical engineering and mechanical engineering departments produced 48.8705 and 62.8401 degrees more than chemical engineering, respectively. Astronomy, geosciences, and physics, on average, produced 32.1684, 27.2821, and 37.8097 degrees fewer than chemical engineering, respectively. The numbers of degrees produced by civil engineering and chemistry were not significantly different from that produced by chemical engineering. That academic departments in engineering produced more bachelor's degrees than their counterparts in physical sciences could be explained, in part, by the fact that employment opportunities were more limited for bachelor's degree holders in physical sciences, and by the fact that jobs in this field more often required doctoral study. However, a larger part of the explanation probably more simply had to do with differences in production functions of engineering and physical science departments—differences in their "ways of producing graduates" that had evolved over time and the respective resources that had been made available to them.

Across the two fields, the degree production at the master's level showed different patterns from those at the bachelor's level. As can be seen from table 6 above, the numbers of tenured/tenure-track faculty and other regular faculty were significantly and positively associated with the number of master's degrees produced. On average a one-unit increase in the numbers of FTE instructional tenured/tenure-track faculty and other regular faculty led to an increase of 0.7995 and 2.7344 units in the master's degree production, respectively. This finding was strengthened by a significant and positive relationship of the graduate individualized instruction student credit hours by tenured/tenure-track faculty and other regular faculty with the number of master's degrees produced. A one-unit increase in the numbers of graduate individualized instruction student credit hours by tenured/tenure-track faculty and other regular faculty was significantly associated with an increase of 0.1646 and 0.4849 units in the master's degree production, respectively. The per-FTE faculty compensation and separately-budgeted faculty research expenditures did not have significant relationships with the number of master's degrees produced. Similarly, coefficients of the year dummy variables were not significant at this award level due, perhaps, to the limited data years of the study.

The coefficients of the dummy variables for academic departments in engineering and physical sciences revealed some interesting findings. Civil, electrical, and mechanical engineering departments each produced 30.4969, 66.3991, and 25.851 degrees more than chemical engineering, respectively. Chemistry and physics—two academic departments in physical sciences—each produced 18.3117 and 9.4882 degrees fewer than chemical engineering. Astronomy and geosciences—another two academic departments in physical sciences—did not significantly produced more master’s degrees than chemical engineering. These findings were expected because generally bachelor’s degree holders in engineering were more likely to pursue master’s degree programs in order to be more competitive in the job market. In physical sciences bachelor’s degree holders were more likely to pursue doctoral study as employment opportunities for someone with a bachelor’s or master’s degree were more limited in this field.

The degree production at the doctoral level basically confirmed the arguments that had been made at the bachelor’s and master’s degree levels. As can be seen from table 6 above, the number of tenured/tenure-track faculty was significantly and positively associated with the number of doctoral degree produced whereas the number of other regular faculty had a significantly negative relationship with the doctoral degree production. On average a one-unit increase in FTE instructional tenured/tenure-track faculty led to an increase of 0.7734 units in the number of doctoral degrees produced, and a one-unit increase in FTE instructional other regular faculty was associated with a decrease of 1.4614 units in the doctoral degree production. Viewed in line with previous findings at the bachelor’s and master’s levels, the findings at the doctoral degree level suggested that in engineering and physical sciences tenured/tenured track faculty focused more on the production of graduate degrees (master's and doctoral) whereas the increased importance of non-tenure-track faculty (for example, other regular faculty) could have been seen at the bachelor's and master's levels.

That the per-FTE graduate individual instruction student credit hours by tenured/tenure-track faculty had a significant and negative relationship with the number of doctoral degrees produced. This was a somewhat puzzling result, as one would assume that if indeed dissertation and research credit hours in fact were classified as individualized instruction, then there would be a positive relationship to degrees produced. What this result probably represented was simply a direct reflection of facts: The more a doctoral degree program was constituted of individualized instruction, the fewer degrees were produced. In other words greater reliance on non-classroom instruction is characteristic of universities that produce fewer degrees in the physical sciences and engineering. Similar to the findings at the bachelor's and master's degree levels, the per-FTE faculty compensation and separately-budgeted faculty research expenditures were not significantly associated with the doctoral degree production. The dummy variable coefficient for year 2007 was not significant, and that of year 2006 was marginally significant at the 10% confidence level.

The coefficients of dummy variables for academic departments in engineering and physical sciences revealed a different pattern from those at the bachelor's and master's levels. As can be seen from table 6, the coefficients of dummy variables for civil, electrical, and mechanical engineering—academic departments in engineering—were significantly negative. On average civil, electrical, and mechanical engineering produced 4.2687, 8.8171, and 8.0003 fewer degrees than chemical engineering, respectively. Similarly, astronomy, geosciences, and physics—academic departments in physical sciences—produced 7.0931, 9.0037, and 11.4243 degrees fewer than chemical engineering. The number of doctoral degrees produced by chemistry—another department in physical sciences—was not significantly different from that produced by chemical engineering. That engineering departments produced fewer degrees at the doctoral level could be explained by the fact that there might have been more job opportunities for bachelor's or master's degree holders in engineering. The lower numbers of doctoral degrees produced by academic departments in physical sciences could also be explained by labor market condition: although the doctoral degree is often considered as the "terminal" degree in physical sciences, academic departments in this field produced fewer doctoral degrees probably due to limited market demand, as compared to chemical engineering (the base category).

CHAPTER 9

SUMMARY AND IMPLICATIONS

Background

That scientists and engineers play a central role in American economic life with their innovations cannot be argued. The last century gives us vivid examples:

> The past 20th century witnessed the incredible ingenuity of the country. From Ford's Model T in 1908 and on to the washing machine (1911), refrigerator (1924), microwave oven (1953), modem (1958), hand-held calculator (1967) and the personal computer (1981), American innovations have transformed our nation, again and again, creating whole new industries and occupations. Going forward, new innovations will continue to be critical, both in maintaining a solid industrial base and increasing our standard of living. (Talking Points, STEM Education, www.stemedcaucus.org)

To maintain its position in the 21st century, it is essential that the U.S. continue as the world's leading innovator. Innovativeness of a country depends on a work force with solid knowledge of science, technology, engineering, and mathematics. Combined effects of increasing global competition, continuous technological advances, scientific and engineering work force retirements, and reduced interests in STEM majors, however, make it difficult for American universities to produce enough scientists and engineers to meet the growing demand for skilled employees in these fields. The following numbers illustrate this point:

> In 1960, 17 percent of U.S. bachelor or graduate degrees were awarded in engineering, mathematics or the physical sciences. By 2001 the number had dropped to just 8 percent and represented more than a 50 percent decline. In 2001 the U.S. produced just 148,000 graduates in these critical areas—the smallest number in two decades. At this rate the country's educational system will not be able to meet the economy's workforce demands by the end of this decade. The same general pattern exists at the graduate level, where less than 10 percent of degrees conferred are in engineering, mathematics and computer science, placing the U.S. 20th internationally on this measure. Further, more than 40% of doctoral students in engineering, mathematics and computer science in the U.S. are international students, and in several fields the percentage of international students is more than 50% (Talking Points, STEM Education, www.stemedcaucus.org).

This problem gave rise to a fundamental national policy question: in an era of declining support by state governments, historically their funding "base," how can universities educate more efficiently the large numbers of scientists and engineers that are required to meet the challenges of intensive international competitiveness?

Summary of Research Questions

This study first examined the degree production of a sample of major AAU public universities at three award levels (bachelor's, master's, and doctoral) in five fields of science and engineering (engineering, physical sciences, mathematical and computer sciences, life sciences, and social sciences). Based on findings at this level, additional analyses were conducted of degree production for the same three award levels within academic departments in the fields of engineering and physical sciences. More specifically, two following research questions were examined:

Research question 1: Holding degree quality constant, to what degree do faculty research expenditures and faculty instructional time allocation explain the number of degrees awarded by degree production level (bachelor's, master's, and doctoral) in five fields—engineering, physical sciences, mathematical/computer sciences, life sciences, and social sciences?

Research question 2: Holding degree quality constant, to what degree do faculty research expenditures and faculty instructional time allocation explain the number of degrees awarded by degree production level (bachelor's, master's, and doctoral) in academic departments within two fields—engineering and physical sciences?

Summary of Findings and Discussion

The field-level production of bachelor's, master's, and doctoral degrees in five fields of science and engineering (engineering, physical sciences, mathematics/computer sciences, life sciences, and social sciences)

The production functions at three different levels (bachelor's, master's, and doctoral) revealed that tenured/tenure-track faculty were vital in producing degree holders. The production functions at these three levels, however, also showed that other types of faculty—other regular faculty, supplemental faculty, and teaching assistants—also played an increasingly important role in the production process. To be more specific, tenured/tenure-track faculty assumed an important role in the production process at all award levels (bachelor's, master's, and doctoral) whereas the role of other regular faculty was significant in the production of bachelor's and master's degrees. Supplemental faculty and teaching assistants were also important in the production of bachelor's degrees.

The study also revealed that there were significant differences among five fields of science and engineering (engineering, physical sciences, mathematical/computer sciences, life sciences, and social sciences) at each of the three production levels. At the bachelor's level, more degree holders were produced by social sciences, engineering, and life sciences whereas fewer were produced by physical sciences and mathematical/computer sciences. At the master's level, the numbers of degrees produced in engineering and life sciences were positively larger than the number of degrees produced in social sciences (the base category). The numbers of degrees produced by physical sciences and mathematical/computer sciences, however, were not significantly different from that by social sciences. At the doctoral level, engineering, physical sciences, and life sciences produced more degrees than social sciences. The number of degrees produced by mathematical/computer sciences was lower than the number of degrees produced by social sciences. Given a limited number of universities in the sample (12 universities) over a short period of time (2005-2007), it could be said that the findings above applied only to the universities in the sample during the time period under consideration.

The differences among the five fields of science and engineering could be explained, for the most part, by employment opportunities for degree holders in each field. For example, engineering produced more undergraduate degrees probably at least in part because there were more job opportunities for bachelor's degree holders in this field. That social sciences were among the fields that produced the most bachelor's degrees could also be explained, again at least in part, by the fact that the curricular in other fields were more demanding, or that more students simply preferred to work in areas where there was more “human interaction.” At the master’s degree level, engineering produced more degree holders, again probably for labor market reasons in this field at this award level. Physical sciences and life sciences were the two fields that produced the largest numbers of doctoral degrees probably due to the fact that employment vacancies in these fields, which mostly involved teaching and/or basic research, more often required doctoral degree holders.

Per-FTE faculty compensation was significantly and positively correlated with the numbers of bachelor’s, master’s, and doctoral degrees produced. Probably universities that paid their faculty more were those that had more resources to take in more undergraduate, master’s, and doctoral students and therefore were able to produce more degrees at these three award levels. Per-FTE separately-budgeted research expenditures did not have a significant effect on the production of bachelor’s and master’s degrees, but the variable was significantly and positively associated with the production of doctoral degrees. This could be explained by the positive relationship between research funds of faculty and the number of doctoral students they were able to take in. As faculty gained more research funds, their academic departments could accept more doctoral students into their programs and therefore would produce relatively more doctoral degree holders.

The departmental-level production of bachelor’s, master’s, and doctoral degrees in engineering (civil, electrical, mechanical, and chemical engineering) and physical sciences (astronomy, chemistry, geosciences, and physics)

Findings at the departmental level in the two fields engineering and physical sciences—the focus of this dissertation—revealed that the role of tenured/tenure-track faculty was essential in the production of bachelor's, master's, and doctoral degrees. Other regular faculty also played an important role in the production of master's degrees. The bachelor's degree level saw a relative decrease in the involvement of tenured/tenure-track faculty and no significant role for non-tenure-track faculty in the production process. There were several reasons that the growing number of non-tenure-track faculty was probably understated, at least in engineering. First, undergraduate students in engineering still took foundation courses (mathematics, physics, chemistry, and writing) in arts and sciences colleges, which made very substantial use of non-tenure-track faculty. In short academic departments in engineering were "outsourcing" part of their production to non-tenure-track faculty appointed elsewhere. Second, the substantial research funds in engineering led to an increased number of research scientists therein—individuals who sometimes participated in instruction. These scientists were, however, rarely recorded as non-tenure-track faculty even when they did teach (Cross & Goldenberg, 2009, p. 27).

The study also revealed significant differences among academic departments in engineering (civil, electrical, mechanical, and chemical engineering) and physical sciences (astronomy, chemistry, geosciences, and physics) at each of the three production levels. At the bachelor's level, departments in engineering generally produced more degrees than their counterparts in physical sciences. To be specific, electrical engineering and mechanical engineering departments produced more degrees than chemical engineering (the base category). Astronomy, geosciences, and physics —academic departments in physical sciences—produced fewer degrees than chemical engineering. The numbers of degrees produced by civil engineering and chemistry were not significantly different from that produced by chemical engineering. These findings could be explained by the fact that employment opportunities were more limited for bachelor's degree holders in physical sciences, and jobs in this field more often required doctoral study.

At the master's degree level, the analysis revealed findings similar to those at the bachelor's level: engineering departments generally produced more degrees than departments in physical sciences. Specifically, civil, electrical, and mechanical engineering produced more degrees than chemical engineering whereas the numbers of degrees produced by chemistry and physics—academic departments in physical sciences—were smaller than that of chemical engineering. It is known that master's degrees are more often the "terminal" degree in engineering, again a labor market condition. In chemistry or physics, bachelor's degree holders were more likely to pursue doctoral study as employment opportunities for someone with a bachelor's or master's degree were relatively more limited.

At the doctoral degree level, apparently academic departments in engineering and physical sciences produced fewer degrees than chemical engineering (the base category). In engineering the master's degree is often considered as the "terminal" degree, and there might have been more job opportunities for bachelor's or master's degree holders. This could explain why fewer doctoral degrees were produced by academic departments in this field. Although the doctoral degree is often considered as the "terminal" degree in physical sciences, academic departments in this field produced fewer doctoral degrees, as compared to chemical engineering (the base category), probably due to limited market demand. Given a limited number of universities in the sample (12 universities) over a short period of time (2005-2007), it could be said that the findings above applied only to the universities in the sample during the time period under consideration.

Implications of the Study

The findings of this study present several implications for various stakeholders: university administrators, academic department heads, and federal and state policy makers. As can be seen from the above analysis, non-tenure-track (i.e., non-tenure-eligible and part-time) faculty are playing an increasingly important role in producing degrees, especially at the bachelor's and master's levels. Contrary to common thinking, on the demand side academic departments appear to hire non-tenure-track faculty for other reasons than the fact that non-tenure-track faculty are less expensive: academic departments may hire non-tenure-track faculty in order to bring professional expertise and experience to the academia (for example, writers, lawyers, computer animation experts), to meet temporary needs (for example, to replace other faculty that are temporarily on leave, or to cope with temporary increases in enrollment), or to meet teaching demand in certain courses that tenured faculty resist teaching (especially at the introductory level) (Cross & Goldenberg, 2009, p. 31). On the supply side, some faculty are on the non-tenure-track not because they cannot get tenured/tenure-track positions. Typically, these faculty are full-time employees (business executives, engineers, mathematicians, social scientists), and they may simply find working in the academic environment personally rewarding. Also, some non-tenure-track faculty are artists who would like to devote most of their time to their artistic careers but also seek greater financial stability by working as part-time instructors (Cross & Goldenberg, 2009, pp. 77-78).

The increasingly important role of non-tenure-track faculty poses several challenging questions to university administrators and academic department heads. First, are non-tenure-track part-time faculty less engaged with students and thus may be less effective in promoting student learning (Geiger, 2008)? This is not an easy question to answer because it involves several issues. As pointed out by Cross and Goldenberg (2009), non-tenure-track faculty do not demonstrate low morale or job dissatisfaction**;** in some areas their job satisfaction is equal or even higher than that of tenured track faculty (p. 76). Problems that non-tenure-track faculty face include job security and work condition. The former is always listed as one of the top concerns of non-tenure-track faculty, and more support for part-time instructors (for example, office space, equipment, and access to employee benefits) has always been an issue (ibid., pp. 107, 112). According to some, teaching skills of part-time instructors are also a major weakness that should be addressed (Wickun & Stanley, 2000). Another concern is inadequate investment by universities in the intellectual growth of non-tenure-track faculty, therefore making it difficult for them to keep up with the latest developments in their fields (Geiger, 2008, p. 13). Efforts towards improving job security, work condition, teaching skills, and intellectual development for non-tenure-track faculty are, therefore, among measures that help enhance the engagement of non-tenure-track faculty with students and benefit the teaching and learning process in the long run.

Second, should non-tenure-track faculty play a role in shared academic governance with tenured/tenure-track faculty, given the former’s increasingly important role in teaching activities and the degree production process? This is a challenging question because non-tenure-track faculty and tenured/tenure-track faculty are often different from each other in terms of their interests and responsibilities (Cross & Goldenberg, 2009, p. 141). The major interests and responsibilities of traditional faculty are more diverse than those of non-tenure track faculty, who tend to specialize in the areas of teaching or research whereas the former are involved not only in teaching and research but also service, including academic governance. If non-tenure-track faculty were to share governance with tenured/tenure-track faculty, what would be the right “formula” for doing so? If non-tenure-track faculty were to continue *not* to share governance with tenured/tenure-track faculty, what would be the consequences over the long term? Might the performance of non-tenure-track faculty be affected adversely? If so, to what extent? And to what extent might this effect eventually undermine the work environment in academic departments?

Perhaps the most important implication for university administrators and department heads has to do with the optimal balance between these two types of faculty—non-tenure-track teaching faculty and tenured/tenure-track research faculty. Prestige maximization has long been considered to be the primary driver of university behavior, broadly speaking (Geiger, 2008, p.1). Prestige maximization often is seen as deriving primarily from research faculty, from the research grants they receive and the publications they produce. But what role do non-tenure-track faculty play in the production in these “outcomes”? The choice may not be in deciding how many “research faculty stars” to recruit but rather in taking a broader view of optimal department “production functions,” to include the optimal mix of non-tenure-track personnel. Clearly many, if not most, academic departments have considered this question and have opted for a richer mix of non-traditional faculty members. Presently, the fundamental issue may be how to secure flexibility in making additional changes in personnel mixes. Given the nature of departmental academic governance, one might assume that tenured/tenure-track faculty are more likely to seek the hiring of people like themselves to the detriment of overall unit effectiveness and efficiency. Conversely, financial pressures may result in hiring and retaining too many non-traditional personnel in lieu of research faculty. This issue is often addressed in the literature. Cross & Goldenberg (2009, pp. 47-48) see the present situation as allowing tenured/tenure-track faculty to teach in their areas of expertise and devote more time to their research while allowing the meeting of teaching responsibilities through the hiring of less expensive, quicker to recruit, non-tenure-track faculty who assume heavier teaching loads. At the least, the question of "mix optimality" should be addressed directly.

The increasingly important role of non-tenure-track faculty illustrates the changing resource dependency environment and how adaptations are being made. Geiger (2008) points out that "public universities are now heavily dependent on tuition revenues, just like privates." The increasing reliance on tuition from students emphasizes the need to maintain both the quality and "quantity" of teaching, and thus the increasing importance of non-tenure-track faculty to meet teaching demands. In their work on resource dependency theory, Pfeffer and Salancik (2003) state "it is the fact of the organization's dependence on the environment that makes the external constraint and control of organizational behavior both possible and almost inevitable" (p. 43). These relationships are sharply illustrated by the increasing use of non-traditional faculty.

One of the most important findings of this research is that there are significant differences among five fields of science and engineering and among academic departments in engineering and physical sciences, and these differences can be explained largely by the rigor of the curricula and by market demands. This finding means that despite similarities that may exist among them, each field and each academic department has its own production function with its own culture and traditions. For example, introductory-level math courses traditionally are taught in colleges of arts and sciences, presumably for efficiency and effectiveness reasons. Another example is that some chemistry courses, such as organic chemistry, are taken not only by chemistry majors but also by pre-medicine students. One effect is the efficiency gained through large classes. An important implication from such examples is what these different production functions may tell us about optimality in other fields/academic departments. Are other efficiencies possible without loss of effectiveness? How might these opportunities be identified? How can STEM departments benefit from examining themselves more closely by reflecting upon the production functions of other STEM units? How might production functions of different fields/departments change over time? How does the federalization of research activities influence universities' degree production?

Finally, a potentially very important issue has to do with the changing emphasis within research universities on targeting funding on fields that promise greater immediate financial "returns" than do other fields, which may be vitally important to society generally. The increasing emphasis being given to STEM funding during the recent relative decline in public funding of higher education raises important questions that apparently are not being addressed seriously, if at all. First, what are the facts regarding changes in funding for non-STEM fields such as the arts and the humanities? Second, what are the long-term effects upon society, broadly speaking, of what Slaughter and Leslie (1997) called "academic capitalism?" Whereas it is difficult to imagine that anyone would argue for less attention being given to these areas, there appears to have been little recent attention to the consequences of their funding declines.

CHAPTER 10

FURTHER RESEARCH

This study explored the degree production function of a sample of AAU public research universities at the field and departmental levels. The readily available control for quality of academic departments in the data set was per-FTE faculty compensation; better proxies were not available. Although faculty's publications likely would have been superior as a control and such data are available in the ISI Web of Knowledge, the names of faculty members would have been required to retrieve the data. The names of faculty members, however, were not available for this research. Future research would likely benefit from such better controls in this regard.

Another topic for additional research has to do with the limited faculty time allocation data available in the data source. This research, which was limited to faculty's in-class time allocation (as proxied by student credit hours), serves as a starting point for examining how faculty time allocation may influence the degree production process at the bachelor's, master's, and doctoral levels. Faculty's time use, of course, consists of both in-class and out-of-class interaction with students. Out-of-class interactions no doubt have important positive impacts on the learning process and production of degrees, especially at the graduate level where faculty and students often interact in ongoing research projects. Inclusion of such data could offer important additional insight into degree production processes. An exemplar study that took into account both in-class and out-of-class faculty time allocation among all areas of faculty responsibility—teaching, research and service--as well as academic department heads' insights was an NSF-funded research project (grant number 9628325) by Leslie, Oaxaca, and Rhoades (1999). A study of connections between these faculty time allocation and degree production should yield important understandings in the same areas investigated in the present research.

Lastly, due to the limited time span of the data (2005-2007), this study did not take into account possible lagging effects of faculty time allocation, faculty compensation, and faculty research expenditures on the degree production process. If data over a wider time span were available, the introduction of lagging effects into analytical models would probably result in interesting findings. Also, for purposes of federal and state policy, it would be desirable for private universities to be examined, too, given several important differences between public and private universities. A comparative study of the two sectors would be both useful and intriguing.

This research has provided fundamental analysis of field and departmental degree production and shown the influence of variations in faculty time allocation, faculty compensation, and faculty research expenditures. Although some findings largely reflect "common sense" (for example, the important role of tenured/tenure-track faculty in the production of bachelor's, master's, and doctoral degrees), others provide empirical evidence of matters that should gain the attention of major stakeholders in higher education: the increasingly important role of "other" regular faculty, supplemental faculty, and teaching assistants in producing degrees at the bachelor's and master's levels; reduced teaching loads of tenured/tenure-track faculty at the bachelor's and master's levels and their focus on research and teaching doctoral students; the positive relationship between faculty research expenditures and the number of doctoral degrees produced; and most importantly, the significant differences among five fields of science and engineering and among academic departments within the two fields of physical sciences and engineering. Future analysis of these issues will help answer challenging questions regarding resource allocation, shared governance, and optimal production functions in each field/academic department.

APPENDIX

Crosswalk between NSF Fields of Science and Engineering and the National Center for Education Statistics (NCES) Classification of Instructional Programs (4-digit CIP 2000)

Engineering	
04.01	Engineering, General
14.02	Aerospace, Aeronautical and Astronautical Engineering
14.03	Agricultural/Biological Engineering and Bioengineering
14.04	Architectural Engineering
14.05	Biomedical/Medical Engineering
14.06	Ceramic Sciences and Engineering
14.07	Chemical Engineering
14.08	Civil Engineering
14.09	Computer Engineering, General
14.10	Electrical, Electronics and Communications Engineering
14.11	Engineering Mechanics
14.12	Engineering Physics
14.13	Engineering Science
14.14	Environmental/Environmental Health Engineering
14.18	Materials Engineering
14.19	Mechanical Engineering
14.20	Metallurgical Engineering
14.21	Mining and Mineral Engineering
14.22	Naval Architecture and Marine Engineering
14.23	Nuclear Engineering
14.24	Ocean Engineering
14.25	Petroleum Engineering
14.27	Systems Engineering
14.28	Textile Sciences and Engineering
14.31	Materials Science
14.32	Polymer/Plastics Engineering

14.33	Construction Engineering
14.34	Forest Engineering
14.35	Industrial Engineering
14.36	Manufacturing Engineering
14.38	Surveying Engineering
14.39	Geological/Geophysical Engineering
14.99	Engineering, Other
Physical Sciences	
40.01	Physical Sciences
40.02	Astronomy and Astrophysics
40.04	Atmospheric Sciences and Meteorology
40.05	Chemistry
40.06	Geological and Earth Sciences/Geosciences
40.08	Physics
40.99	Physical Sciences, Other
Mathematical/Computer Sciences	
11.01	Computer and Information Sciences, General
11.02	Computer Programming
11.03	Data Processing
11.04	Information Science/Studies
11.05	Computer Systems Analysis
11.07	Computer Science
11.08	Computer Software and Media Applications
11.09	Computer Systems Networking and Telecommunications
11.10	Computer/Information Technology Administration and Management
11.99	Computer and Information Sciences and Support Services, Other
14.37	Operations Research
27.01	Mathematics
27.03	Applied Mathematics
27.05	Statistics
27.99	Mathematics and Statistics, Other
30.08	Mathematics and Computer Science

Life Sciences	
01.03	Agricultural Production Operations
01.07	International Agriculture
01.09	Animal Sciences
01.11	Plant Sciences
01.12	Soil Sciences
03.xx	Natural Resources and Conservation
04.06	Landscape Architecture
19.05	Foods, Nutrition, and Related Services
26.01	Biology, General
26.02	Biochemistry, Biophysics and Molecular Biology
26.03	Botany/Plant Biology
26.04	Cell/Cellular Biology and Anatomical Sciences
26.05	Microbiological Sciences and Immunology
26.07	Zoology/Animal Biology
26.08	Genetics
26.09	Physiology, Pathology and Related Sciences
26.10	Pharmacology and Toxicology
26.11	Biomathematics and Bioinformatics
26.12	Biotechnology
26.13	Ecology, Evolution, Systematics and Population Biology
26.99	Biological and Biomedical Sciences, Other
30.11	Gerontology
30.19	Nutrition Sciences
30.24	Neuroscience
51.02	Communication Disorders Sciences and Services
51.04	Dentistry
51.07	Health and Medical Administrative Services
51.10	Clinical/Medical Laboratory Science and Allied Professions
51.12	Medicine
51.16	Nursing
51.17	Optometry

51.19	Osteopathic Medicine/Osteopathy
51.20	Pharmacy, Pharmaceutical Sciences, and Administration
51.21	Podiatric Medicine/Podiatry
51.22	Public Health
51.24	Veterinary Medicine
51.99	Health Professions and Related Clinical Sciences, Other
Social Sciences	
04.03	City/Urban, Community and Regional Planning
05.xx	Area, Ethnic, Cultural, and Gender Studies
16.01	Linguistics
43.01	Criminal Justice and Corrections
44.02	Community Organization and Advocacy
44.04	Public Administration
44.05	Public Policy Analysis
44.99	Public Administration and Social Service Professions, Other
45.01	Social Sciences, General
45.02	Anthropology (Social and Cultural only)
45.03	Archeology
45.05	Demography and Population Studies
45.06	Economics
45.07	Geography and Cartography
45.09	International Relations and Affairs
45.10	Political Science and Government
45.11	Sociology
45.12	Urban Studies/Affairs
45.99	Social Sciences, Other
52.06	Business/Managerial Economics

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