Why is Math Cheaper than English?
Understanding Cost Differences in Higher Education

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Abstract

This paper establishes five new facts about instructional costs in higher education using department-level data from a broad range of institutions. Costs vary widely across fields, ranging from electrical engineering (90 percent higher than English) to math (25 percent lower). This pattern is largely explained by differences in class size and faculty pay. Some STEM fields experienced steep declines in expenditures over the past 17 years while others saw increases. Changes in class size and teaching loads alongside a shift toward contingent faculty explain these trends. Finally, the association between online instruction and instructional costs is statistically indistinguishable from zero.

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I. Introduction

Investment in education fosters human capital development, shapes long-term economic growth, and influences socioeconomic mobility (Goldin & Katz, 2008; Autor, 2014). At the postsecondary level, the private return to this investment varies widely by field of study, with science and engineering fields generally having a higher labor market payoff than the humanities and social sciences (e.g., Altonji, Arcidiacono, & Maurel, 2016; Kirkebøen, Leuven, & Mogstad, 2016). These outcome differences have prompted policymakers to promote enrollment in high-earning fields through various direct and indirect incentives to institutions and students, such as targeted scholarships and performance-based funding. However, we know very little about the economic cost of this investment or the resource consequences of steering more students into these fields. Further, given the strong evidence on the importance of resources in both K-12 and postsecondary education (Jackson, Johnson, & Persico, 2016; Bound, Lovenheim, & Turner, 2010; Cohodes & Goodman, 2014; Deming & Walters, 2017), a better understanding of institutional choices about spending is foundational to improving college quality.

In this paper we use department-level data on costs (expenditures), outputs, and factors of production for nearly 600 four-year institutions from 2000 to 2017 to provide a comprehensive descriptive analysis of instructional costs in higher education. We estimate differences in instructional costs by field, characterize associations between production factors such as class size and faculty workload and these cost differences, and document trends over time in field-specific costs. Our data include undergraduate, graduate, and professional school instruction for a diverse sample of public and private four-year institutions that are broadly representative of all four-year institutions nationally. Prior work on college costs largely consists of institution-level analyses and case studies of elite private institutions, and thus cannot illuminate differences across fields for the institutions attended by most students.

We establish five new facts about college costs. First, there are substantial cost differences across fields of study. Using English as a benchmark, instructional costs per student credit hour (SCH) range from 92 percent higher for electrical engineering to 25 percent lower for mathematics. The average English course with 20 students incurs approximately $13,000 in instructional expenses, so these percentage differences reflect substantial levels of resources. Costs are generally higher in fields where graduates earn more and in pre-professional programs. Second, most of the cross-discipline patterns can be explained statistically by large differences in class size and, to a lesser extent, differences in average faculty pay (itself a function of salaries and mix of faculty type/rank). Teaching loads and other (non-personnel) expenditures explain little of the instructional cost differences across fields. Further, some fields with highly paid faculty (like economics) offset high wages with large classes, resulting in costs that are comparable to English despite higher faculty pay. Differences in production technology that, for example, enable some departments to offset higher salaries with larger classes are thus a key determinant of cost differences in postsecondary education.

Third, cost differences have evolved over time. Some STEM fields – mechanical engineering, chemistry, physics, and nursing – experienced steep declines in spending over the past 17 years while others saw increases. Fourth, these trends are explained by large increases in class size (mechanical engineering, nursing) and increases in faculty teaching loads (chemistry) accompanied by a shift in faculty composition toward contingent faculty. Finally, we fail to detect a relationship between the presence or extent of online instruction and cost.

A better understanding of cost differences across fields informs policy concerns as well as long-standing topics in economics. On the policy front, institutions and states could explicitly take the large cost differences across fields into account when setting prices and allocating resources. Many public institutions charge students differentially by college or field (Stange, 2015), and some states recognize cost differences in their appropriations formulas, but these cost differences are present even for states and institutions that do not use such practices.

Knowledge about field-specific instructional costs and cost drivers improves our ability to characterize education production functions at the postsecondary level. To the extent that such production function differences by field are also reflected in secondary education, where class sizes and salaries tend to vary less, this would imply that secondary schools may not be optimizing with respect to class size or teacher pay. Our results also underscore the potential wedge between the social and private returns to higher education. That is, the social return to investment in high-earning fields may be lower than wage premiums suggest because high-return fields also tend to be more costly to teach. This point was made in earlier work by Altonji and Zimmerman (2019), but we broaden the scope of institutions for which we now have evidence of this fact. This highlights the need for policymakers to consider the cost implications of changes in the mix of fields students study.

Our analysis of cost drivers begins to inform how postsecondary institutions could temper cost escalation. College prices have grown by 40 percent between 2005 and 2015 (College Board, 2015), increasing the share of postsecondary costs shouldered by students and their families to nearly half (Desrochers & Hurlburt, 2016) and shifting postsecondary enrollment away from four-year public universities and toward two-year colleges and less selective institutions (Hemelt & Marcotte, 2016). Given these trends, a number of initiatives aim to "stretch the higher education dollar" (Kelly & Carey, 2013; NASBO, 2013). In Texas, some colleges answered former Governor Rick Perry's challenge to offer a $10,000 college degree by creating programs that combine high school, community college, and four-year college instruction (Seligman, 2012). The expansion of online learning technology may also lower costs, at least among the least selective colleges (Deming, Goldin, Katz, & Yuchtman, 2015; Bowen, 2012). In Wisconsin, former Governor Scott Walker proposed increased faculty teaching loads as a way to control costs (DeFour, 2015). Our work suggests that differences in production technology enable some departments to take different approaches to cost management, from changing the mix of faculty to increasing class size. This implies that a one-discipline-fits-all approach to addressing cost escalation is likely misguided and ineffective. An important caveat is that we focus on direct instructional expenditures and therefore abstract from other forms of expenditures by institutions that are shared across departments, such as student services or administration.

The paper unfolds as follows. The next section situates our study within prior theoretical and empirical research on postsecondary costs, with a focus on work that drills below the institution level. Section III describes our data and samples. Section IV presents cross-sectional cost differences by field of study, and Section V documents how these differences have evolved over time. In Section VI we dig more deeply into these patterns by exploring the roles of instructor type and class size. Online instruction has been touted as one way that institutions can bend the cost curve. In Section VII we describe the adoption of online instruction and its association with costs for a much larger and diverse sample than has been examined in prior work. We conclude with a discussion of the implications of our work in Section VIII.

II. Background

A. Theories of Costs and Implications for Cross-Field Differences

Scholars have long noted the tendency for postsecondary costs to rise faster than economy-wide costs over the long term (Bowen, 2012). A range of explanations has been posited for this phenomenon, including the curse of labor-intensive industries in which the substitutability of capital for labor is low (the "cost-disease" theory coined by Baumol and Bowen (1966))[1], the proclivity of colleges to act like revenue maximizers in effort to compete in the murkily defined race of prestige (Bowen, 1980), the temptation to spend on student amenities (Rubin, 2014; Jacob, McCall, & Stange, 2018), and the expansion of unnecessary administrative positions. These theories tend to focus on macro-level phenomena and institutional behavior. However, they also provide insights about departments, the postsecondary unit chiefly responsible for instruction. Below we sketch an informal model of decision-making for individual academic departments (programs), which provides a framework for organizing the cost factors we explore empirically.

Programs produce a set of outputs, such as quality-equivalent units of undergraduate instruction or research publications, using a large set of inputs, such as faculty of different types, classrooms, office space, technology, and laboratories.[2] Programs choose inputs to maximize some objective subject to a production function, a department-level budget constraint, taking input prices as given. There may also be adjustment frictions that restrict

[1] The "cost disease" theory was originally proposed in the context of performing arts (Baumol & Bowen, 1966). Since higher education is labor intensive and wages are set on a national market, instructional costs in higher education tend to rise faster than in other industries that can more easily substitute capital for labor. Productivity gains are not able to offset wage increases, holding down (or reducing) costs as they do in other industries, particularly manufacturing. The health care industry faces a similar challenge.

[2] We consider the quantity of instructional credits produced (e.g., how many classes students take) and the quality of those instructional credits (e.g., how much students learn) as separate outputs. We do not observe quality measures in our data. The relative value placed on quantity versus quality likely varies across institutions (and possibly programs) and is determined by the objective function.

changes in inputs (i.e., dynamic constraints) in the short term. Variation in the cost of instruction per student across programs can thus be due to differences in any of these elements.

The production function that maps inputs to outputs likely varies across fields. Some subjects require intense interaction between students and faculty to produce a given level of instructional quality while others require costly laboratory sessions. Relatedly, some fields may be able to take advantage of economies of scale and scope. Some departments deliver general education courses for the entire institution, affecting the portion of the marginal and average cost curves faced by the department.[3] Departments offering both undergraduate and graduate programs may experience scope economies, as they can tap graduate students as a pool of lower-cost instructors (e.g., Dundar & Lewis, 1995; Johnes & Johnes, 2016). Such differences necessarily affect optimal class size, faculty mix, faculty teaching load, and non-personnel expenditures – all of which determine cost per unit of instruction.

Though the "cost disease" theory refers to cost growth over time, its logic easily extends to cross-field differences. Higher input prices make instruction of certain fields more expensive; some fields must pay faculty higher salaries to attract them from the non-academic market. However, the extent of substitutability of different inputs in the production process will determine how influential specific input prices are to overall cost differences. For instance, an ability to shift to larger classes without a meaningful reduction in quality in response to high wages will constrain cost differences across fields.

Budget constraints can also vary by program within the same institution. On the revenue side, fields typically housed in separate schools such as Engineering or Business

[3] The data allow us to focus on average instructional costs, but we cannot observe marginal costs.

(compared to the College of Arts and Sciences) have different opportunities for revenue generation due to the use of differential pricing (Stange, 2015) or decentralized budgeting (often referred to as "responsibility centered management"). Both dictate how much of tuition revenue departments can keep. Some states, such as Ohio, Texas, and North Carolina, explicitly provide higher levels of appropriations for certain fields that are perceived to be more costly. Finally, given the large cross-major earnings differences among graduates, some fields will have greater opportunities to raise donations from alumni.[4] These factors alter departments' incentives and potential for revenue generation which is used to fund instruction.

Finally, departments may be subject to frictions that restrict changes in inputs (i.e., dynamic constraints) in response to external shifts in demand. For instance, departments with relatively more faculty with long-term or permanent contracts will have a difficult time reducing faculty size quickly.[5] Contracts also imply that positive and negative demand shocks could have asymmetric effects if hiring a short-term adjunct to teach one additional section is easier than firing a permanent employee. With firing frictions, positive demand shocks would lead production and total cost to increase proportionately, while negative shocks would increase average costs as inputs cannot be reduced proportionately. Transient and long-run shocks also have different implications since contracts make adjustment costly. If a department faces a transient shock (e.g., increased enrollment during a recession), it may need to pay the adjustment costs twice or not adjust at all. Capital is also dynamically constrained, since a university cannot immediately build more or sell land, although a department may be able to adjust its online

[4] Monks (2003) finds empirical support for such differences.
[5] Thomas (2019) models the role of long-term contracts and their influence on the University of Central Arkansas's course offerings.

offerings in response to a shock without adjusting capital.[6] Unfortunately, we are unable to explicitly test for the implications of these constraints, which are unobserved in our data. However, we do look at how costs differ between fields with different enrollment trends.

In theory, programs may differ in their objectives (e.g., valuation of quality versus quantity of teaching or undergraduate instruction versus research output); however, this consideration should be less relevant here given our focus on differences across fields within the same institution.[7] Reputation, admissions, faculty research expectations, and shared norms mostly operate at the level of the institution where tenure decisions, for instance, are ultimately approved by university-wide committees or administrators specifically to enforce institution-wide quality standards.

Throughout the paper, we tie empirical findings back to this simplified model of the academic department.

B. Prior Evidence on Costs in Higher Education

Most prior work on costs in higher education uses institution-level measures from the Delta Cost Project (DCP) and IPEDS, documenting trends over time and differences by type of institution (e.g., Desrochers & Hurlburt, 2016).[8] For instance, Hoxby (2009) demonstrates that institutional spending became more stratified across institutions as the college market became

[6] This is an oversimplification as faculty and capital inputs are discrete, and dynamic contracts make it very difficult to temporarily increase the number buildings or tenure-track faculty.
[7] Prior literature typically assumes that colleges are either profit (Rothschild & White, 1995) or quality (Epple et al., 2006, 2017) maximizing. If universities and programs have similar objectives, assuming programs maximize quality of instruction is consistent with prior work. However, we need not impose this assumption given our data and the purposes of this article. Instead we discuss how well it fits the findings that emerge.
[8] Desrochers and Hurlburt (2016) document changes in spending between 2003 and 2013. They find large increases in total expenditures at research-intensive universities, with smaller increases at public and private institutions less focused on research. Education and related expenses range from almost $38,000 per full-time equivalent (FTE) student at private research-intensive universities, to around $13,000 per FTE at public master’s institutions.

nationalized, with the most selective institutions increasing spending considerably more than the least selective institutions over the past forty years.[9]

This paper builds on very limited prior work on differences in costs across fields and within institutions, and is most closely related to three previous papers. Altonji and Zimmerman (2019) estimate the costs of producing graduates at the program level for the Florida State University System. They report substantive differences in costs by discipline, bookended by engineering and health sciences at the top (with spending of around $450 per credit) and social science, math, business, and psychology at the bottom (with costs ranging from $200 to $250 per credit).[10] These large cost differences cause the earnings differences across fields to be a misleading indicator of the social return on investment across fields.

Johnson and Turner (2009) document large differences in students per faculty across departments for several sets of institutions and the University of Virginia. They find that the number of faculty relative to undergraduate student demand is much higher in sciences and humanities than in core social science fields like economics and political science. While differences in salary, research output, and pedagogy likely explain some of these patterns, they conclude that political frictions constrain universities from dynamically reallocating resources across units in response to student demand. More recently, Courant and Turner (2019) find that departments at two elite public universities facing higher faculty salaries allow larger classes and

[9] Archibald and Feldman (2011) also use aggregate data to explore numerous explanations for cost increases, concluding that the “cost disease” theory goes a long way toward explaining aggregate cost trends. Other explanations – such as administrative bloat and student amenities – do not seem to hold up to scrutiny. “Economy-wide” factors that affect higher education and similar industries rather than “dysfunctional economic behavior at colleges and universities” (p. 113) seem to be most prominent.
[10] There are a few earlier studies that focused on small samples of departments and institutions. Tierney (1980) found that the sciences (biology, chemistry) have costs per student that are 20 percent to 50 percent higher than programs in the social sciences or humanities in 24 liberal arts colleges. Examining 17 departments across 18 public research universities, Dundar and Lewis (1995) found economies of scale for engineering but not for physical sciences. They also found economies of scope in the social sciences, where offering graduate degrees enables departments to employ graduate students as teaching assistants, resulting in cost savings.

more non-faculty teaching. Further, higher-paid faculty within departments teach fewer undergraduates and specialize in graduate instruction.

Our study also builds on detailed case studies of a small number of elite institutions. Clotfelter (1996) investigates Chicago, Duke, Harvard, and Carleton, concluding that the rise in costs during the 1980s was only partially attributable to increased prices of inputs such as faculty salaries and books. Increased spending was mostly explained by broad efforts to improve institutional quality, expand research output, and improve access via financial aid for needy students. Greater instructional costs were mostly driven by affirmative decisions by institutions to pay "for more and better units of the educational services that these institutions always had produced." (Clotfelter, 1996, p. 13). A specific aspect of this is costly investments in new technology – such as computers and physics labs – which have benefited students and faculty and increased research output (Bowen, 2012). Examining Cornell University, Ehrenberg (2002) reaches a broadly similar conclusion: increasing costs reflect a desire to "be the best" on the part of elite research universities, which is consistent with revenue theory and quality maximization, broadly defined. This behavior is unconstrained by typical market forces, as non-profit and public entities do not profit-maximize since they cannot keep any residual surplus of revenue over cost as profit. Ehrenberg (2002) also notes several external and structural forces that fuel this behavior, such as colleges explicitly being rewarded for higher spending in college rankings and shared governance making substantial cost-cutting nearly impossible.

We build on this prior work to make four contributions. First, our focus on within-institution, program-level costs is novel (with the few exceptions noted above) and reflects the reality that "departments constitute the fundamental organizational unit of colleges and universities" (Tierney, 1980, p. 454.)[11] Second, we look at a much larger set of institutions across more sectors. We will later show that some of the patterns seen in prior work do not generalize nationally or to other sectors. Third, using this broader sample, we examine the role of several factors of production such as class size, faculty workload, and online instruction in shaping department-level costs. Finally, we look over a longer and more recent time period. Importantly, Johnson and Turner's (2009) analysis ends before the Great Recession when many states cut higher education funding considerably.

III. Data Sources and Samples

A. The Delaware Cost Study Data

We use data from the National Study of Instructional Cost and Productivity from the University of Delaware (the "Delaware Cost Study"). Since 1998, the study has collected program-level data from over 700 four-year public and private non-profit higher education institutions and some 22,000 programs (institution-CIP4).[12] Each year, institutions report degrees awarded, fall semester instructional activity, and annual expenditure data for each of their academic programs, which are identified at the four-digit CIP code level.[13] Fall instructional activity is measured by faculty full-time equivalents (FTEs), student credit hours, and organized class sections. Institutions report overall and instructional FTEs by faculty type (tenure-track, other regular, supplemental, credit-bearing teaching assistants, and non-credit-bearing teaching assistants). Student credit hours and class sections are disaggregated by instructor type and course level: lower-division undergraduate, upper-division undergraduate, and graduate. Finally,

[11] Academic programs have a great deal of discretion in defining curricula, setting academic standards, and hiring and promoting faculty (Lattuca & Stark, 2009) – all of which shape instructional costs. Adoption of differential tuition (Stange, 2015) and responsibility-centered management (Priest, Becker, Hossler, & St. John, 2002) lend further support to the importance of disaggregating measures of cost to the academic program level.
[12] Appendix Table A1 lists frequently participating institutions. The Delaware Cost Study is currently in the process of creating a formal process whereby outside researchers may access the data.
[13] Appendix Figure A1 provides a copy of the form used by institutions to report these data.

institutions report total direct expenditures for instruction, research, and public service and total undergraduate and graduate student credit hours for the entire academic year.

In this paper, we work with direct instructional expenditures per student credit hour as our main measure of costs, which include salaries, benefits, and non-personnel expenses. In 2015, the Delaware Cost Study added a component to the survey to capture information about online instruction. In that first year of data collection, over 95 percent of participants completed the questions about online courses. The data contain information on online student credit hours by department at the undergraduate and graduate levels.

Institutional participation in the Delaware Cost Study is voluntary. Therefore, we assessed how well our sample matched the broader universe of public and private non-profit four-year institutions operating in the United States.[14] We found that over a third of all institutions had participated in the Delaware Cost Study at least once (34.2 percent) and that these institutions accounted for 60.1 percent of all the degrees awarded between 1998 and 2015. However, institutions do not participate every year and some fail to report data for all of their departments. Accounting for these gaps, we estimate that our sample represents 23.3 percent of all degrees awarded between 1998 and 2015. Coverage is higher for public institutions than private (32.2 percent versus 7.8 percent of degrees, respectively). Public research universities ranked as "competitive" or "very competitive" by Barron's have the highest rates of survey participation. Finally, we find no association between expenditures and participation, after controlling for sector, type, selectivity, size, and revenue, but we do find a positive association for both tuition (among privates) and enrollment (among publics) with survey participation. We

[14] We defined the relevant universe as public or private non-profit bachelor's, master's, and research-intensive doctoral institutions operating in the 50 states and the District of Columbia between 1998 and 2017, from the IPEDS Completions survey. The final universe includes 1,786 institutions that granted 34.9 million degrees.

use this participaption analysis to construct a set of analytical weights that adjusts our sample to resemble the universe of four-year institutions. Appendix B provides a detailed explanation of the coverage analysis and weighting procedure.

B. Analytic Sample

We limit the analytic sample to data collected between 2000 and 2017 from research-intensive, master's, and baccalaureate institutions in the United States.[15] We exclude observations that were missing critical data or had outlying values for the main variables.[16] Our analysis focuses on 20 core fields of study; they represent the largest fields (collectively accounting for more than half of student credit hours) or fields that are particularly salient for institutional leaders and policymakers.[17] Our final sample contains 43,819 institution-year-CIP-4 observations representing 594 institutions, 20 disciplines, and 8,221 unique programs. We use the full sample for our longitudinal analyses and pool years 2015 to 2017 for cross-sectional analyses. The cross-sectional sample includes 6,994 institution-year-CIP-4 observations representing 240 institutions, 20 disciplines, and 3,417 unique programs. Online data are available beginning in 2015 and consist of 238 institutions, 20 disciplines, and 3,358 unique programs across three years.

Using these data, we construct variables that measure costs, outputs, and inputs. Our primary outcome of interest is direct instructional spending per student credit hour, which we

[15] We use Carnegie Classification to identify institution type. We exclude 13 special-focus institutions due to small sample sizes. We also exclude 11 institutions outside the United States and the District of Columbia. Finally, we drop a small number of observations that did not pass a series of basic data validity checks (e.g., negative FTE values were provided).

[16] We define outliers as values greater than the 99th percentile or lower than the 1st percentile of all values grouped by Carnegie Classification and two-digit Classification of Instructional Programs (CIP) codes.

[17] These fields along with CIP codes are listed in Appendix Table A2. The largest fields excluded from our sample are music (2.09%), general business/commerce (2.06%), health/physical education (1.86%) and linguistics (1.8%). The included 20 fields tend to be less expensive than average (expenditure per student credit hour of $240 vs. $297 for excluded fields), likely reflecting their larger scale and focus on lower-division undergraduate education.

construct by dividing annual instructional costs by annual student credit hours. We also calculate this ratio for the personnel expenditures portion of costs.[18] In terms of candidate cost drivers, we calculate faculty per student (overall and by faculty rank level), faculty teaching load (overall and by faculty rank level), and average class size (overall and by student level). Where necessary, we follow IPEDS guidelines for calculating FTEs for faculty and students.[19] We construct a measure of faculty teaching load by dividing the total number of class sections by faculty FTE. To generate a measure of class size, we divide fall student credit hours (excluding individual instruction) by three, assuming the average class is three credits, and then divide this student count by the total number of course sections (excluding additional course sections, such as labs and discussion sections).[20]

C. Descriptive Statistics

Table 1 presents summary statistics for the main variables in the full sample, separately by Carnegie classification.[21] All analyses, summary statistics, figures, and regressions are weighted by the product of the inverse probability of participating and total student credit hours at the program level. This provides estimates that reflect the average student course enrollment in the country. Research-intensive institutions spend more per credit hour, on average, than do master's and baccalaureate institutions. The gap between institutions with the highest research activity and baccalaureate colleges is about $46 per credit hour. This is a sizeable gap relative to the average for all institutions in the sample of $228 per credit hour. Teaching loads are also lower at research institutions. Compared to faculty at baccalaureate institutions, faculty at high-

[18] Before constructing these variables, we convert all cost data to 2016 dollars using the CPI-U.
[19] The student FTE equals 1/3rd of total adjusted part-time student count plus the count of full-time students; faculty FTE equals 1/3rd of total adjusted part-time instructional staff plus the count of full-time instructional staff.
[20] We calculated additional class size variables to use for robustness checks that assume the average course is four credits. Results are similar when we use this higher credit value.
[21] Appendix Table A3 presents the same statistics for the pooled, cross-sectional sample of 2015 to 2017. Patterns are similar.

research institutions teach about one fewer class per semester. Smaller teaching loads may influence undergraduate class sizes, which are larger at high- and moderate-research institutions, respectively, compared to baccalaureate institutions.[22]

These differences likely reflect differences in objective functions. If instruction, rather than research, contributes more to a baccalaureate institution's objective, then holding the production function constant, theory predicts that departments will spend relatively more of their budgets on instructional quality through smaller classes. Similarly, we expect lower teaching loads where research output contributes more to universities objectives.

Figure 1 shows cross-sectional variation in expenditures across different fields. Electrical engineering averages roughly $430 per student credit hour, about $260 more than math. What drives these differences across fields? As a prelude to subsequent analyses, Figure 2 depicts variation in four key determinants of costs at a department level: class size, instructor salary, workload, and non-personnel expenses. There are clearly big differences in these factors of production across fields, particularly in class size (student credit hours per section) and average salary. Below we quantify the individual contribution of each factor to explaining the cross-field cost differences observed in Figure 1.

Finally, Figure 3 depicts average instructional costs per student credit hour from 2000 to 2017, in 2016 dollars. Over this period, real average instructional costs have remained relatively flat, rising roughly 11 percent (or around $25 per credit hour). When we decompose this modest increase into the parts attributable to changes in credit mix across fields and changes in costs per credit hour by field, we see that the bulk of the uptick is explained by changes in costs within

[22] Graduate classes are about the same size across institution type.

field. Though there was a shift in credit mix towards more expensive fields among our 20, the resulting cost growth was quite modest.[23]

As university leaders and policymakers consider initiatives that may alter the mix of credits taken by students across fields – such as policies that aim to increase enrollment in STEM fields or changes to general education requirements – an understanding of cost differences by field is necessary to inform the likely economic consequences. Thus, we now turn to differences in instructional costs by field and explorations of how field-specific costs have evolved over time.

IV. Cross-sectional Differences

A. Cross-Field Differences in Instructional Costs

Using a pooled sample from 2015 to 2017 as a single cross-section, we estimate differences in average direct instructional costs per student credit hour by field of study, using English as the benchmark field. For each field of study, we begin by calculating the within-institution difference between the log of direct instructional expenditures per student credit hour for that field and the same measure for English. We do this for all institutions and disciplines in our sample and then compute grand averages for each field of study, averaging across institutions and weighting by the analytical weight described above.[24]

Figure 4 reports cross-sectional differences in costs across disciplines, net of broad institutional differences in costs. There is substantial variation across fields in average costs. For example, costs associated with each additional SCH are 90 percent (0.64 log points) higher for

[23] As we discuss later, there was some relative growth in more costly fields such as nursing, business, accounting, engineering, and chemistry, among others. Recall that these 20 fields are large and common across postsecondary institutions, but not exhaustive.

[24] See Appendix B for details on the construction of this analytical weight. The results of this exercise are extremely similar to estimates from a regression of logged direct instructional expenditures per student credit hour on field fixed effects (i.e., CIP-4 indicators) and institution fixed effects; to wit, the coefficients on the vector of CIP-4 indicators (where English is the reference discipline).

electrical engineering and 25 percent lower for math, relative to English. Most social science disciplines, math, and philosophy are relatively less costly whereas STEM fields and those with traditionally large pre-professional programs (e.g., nursing) are relatively more costly. This broad conclusion holds across institutions of different control, research intensity, and selectivity.[25] That is, a field like nursing is more expensive than English no matter whether it resides in a private comprehensive institution or a public research-intensive institution. We therefore pool institutions going forward. These patterns are qualitatively consistent with those reported for Florida public universities by Altonji and Zimmerman (2019), but differ from those reported for two elite publics by Courant and Turner (2019).[26]

Which fields are more expensive? Table 2 catalogues a few characteristics of fields ordered by their relative cost. Though several of the more costly fields also tend to have high earnings (e.g., engineering and computer science), there are exceptions to this general pattern. For instance, education and fine/studio arts are among the most costly programs and also the lowest paid. Higher-earning fields being more costly to produce is generally consistent with the university equalizing the ratio of economic benefits and costs across fields, though these measures do not capture the full extent of costs and benefits, nor do they capture them at the margin.

More costly fields also are more likely to have access to additional revenue sources than English departments. In both revenue theory and quality maximization, we expect fields with

[25] Appendix Figures A2 and A3 show cost differences across fields for subgroups of institutions spilt further by control (i.e., public or private) or selectivity. Conclusions about field-specific costs for these subgroups of institutions are mostly similar to what we see in the pooled sample.

[26] Appendix Table A5 directly compares our estimates to those contained in these prior studies. Our ordering of fields by cost is roughly similar to that found by Altonji and Zimmerman (2019), though they were not able to make distinctions by field in the same broad group (e.g., all social science is aggregated). The range of costs across fields is also wider in our representative sample than in their sample. In contrast to our work, Courant and Turner (2019) find that English is by far the most expensive field at the University of Virginia and University of Michigan, though their analysis does not include engineering, nursing, or business.

access to larger budgets to have greater expenditures. Almost all of the most costly fields are typically housed in separate schools or colleges from English, permitting them to generate additional revenue through differential tuition or separate fund-raising efforts from alumni or industry. Finally, many of the more costly fields receive additional state appropriations in Texas and North Carolina, two states with large systems of public institutions for which we obtained detailed information on budgeting formulas.[27]

The final column reports the annual growth of total student credit hours over our sample period, separately by field. English is one of only four fields that is generating fewer credits over time (along with history, education, and fine/studio arts).[28] If asymmetric adjustment frictions were responsible for higher costs, we would expect that faster-growing fields would have lower costs than slow-growing or declining ones. In fact we see the opposite, with many of the more costly fields also being among the fastest growing. Of course, fast-growing fields may also require higher salaries in order to attract faculty, which we address directly below.

B. Why Do Costs Differ Across Fields?

To quantify how these cross-field differences can be explained, in a statistical sense, by individual factors of production, we develop an accounting identity in the spirit of Clotfelter (1996) that allows us to decompose average direct instructional costs per student credit hour for a given program (i.e., field c at institution i) into four distinct components, and take its log:

$$ln\left(\frac{dir\ instr\ exp}{SCH}\right)_{ci} = ln\left(\frac{dir\ instr\ exp}{personnel\ exp}\right)_{ci} + ln\left(\frac{personnel\ exp}{facFTE}\right)_{ci} + ln\left(\frac{facFTE}{sections}\right)_{ci} + ln\left(\frac{sections}{SCH}\right)_{ci} \quad (1)$$

[27] Note that the causal direction is unclear. States are aware of cost differences between fields and thus target additional resources to more costly fields.
[28] Estimated annual growth rates come from a regression model where the log of total student credits is regressed on time (linearly) and time interacted with field, controlling for program (i.e., institution-by-field) fixed effects. Estimates are similar for undergraduate credit hours and if observations are unweighted.

The first factor captures the importance of personnel expenses relative to all direct instructional expenditures. The second term represents average faculty salary, which is determined by the mix of faculty ranks (e.g., tenure-track faculty, fixed-term instructors, adjunct faculty) and average salary conditional on rank. The third term is an inverse measure of faculty workload (i.e., the inverse of class sections taught per FTE faculty member). Finally, the last term captures (the inverse of) class size. Differences in these four cost factors explain variation across programs in costs to deliver a credit hour, or an approximation of the production function. A given program may be more expensive than another because it employs more expensive faculty; because its faculty have a lower average teaching load; because its classes are smaller; or because the department incurs a greater level of other non-personnel instructional expenses (e.g., laboratory expenses in the sciences).[29]

We determine the relative importance of each cost driver in explaining cost differences by field via a series of simulations. Continuing with English as the benchmark field, we predict costs for each of the 19 other disciplines by varying one cost driver at a time and holding the rest constant, at the values for English.[30] Table 3 presents the results of this decomposition. The first column reproduces the unadjusted cost differences from Figure 4. Each subsequent column estimates the contribution of a particular cost driver to the overall cost difference between a given field and English.

[29] Since equation (1) is the log of an accounting identity, a regression version of it ought to produce coefficients on the cost drivers equal to one and a constant equal to zero. However, the time horizon over which the dependent variable is measured differs from the horizon over which the components of the cost drivers are measured: specifically, the outcome is captured over a year-long horizon whereas the cost drivers are captured only for the fall semester. Appendix C describes the implications of these data realities and how we handle them in our analyses. In addition, Appendix Table A4 shows that, in estimations using the cross-section as well as the full panel, the coefficients on the cost drivers are indeed very close to one.

[30] In all analyses, we cluster standard errors by institution and weight observations by the product of total student credit hours and the inverse probability of participating in the survey. This ensures that the sample is approximately representative of instruction across all institutions.

First consider economics, which is approximately 8 percent less expensive than English. Economics faculty are more highly paid than English, and thus if all cost drivers other than average pay were equalized between the two fields, economics would be 0.40 log points more expensive (column 2). On the other hand, economics classes tend to be much larger than English classes, so class size differences make economics 0.51 log points less expensive than English (column 4). Faculty workload is a little lighter in economics than English, so if that were the only difference, economics would be about 3 percent more expensive than English. Putting these findings together, we see that economics departments are able to field classes that are large enough to more than offset the higher salary and (slightly) lower workload of economics faculty, resulting in slightly lower average costs than English.

Mechanical engineering, which is 62 percent more expensive than English (or 0.48 log points), provides a counter example. Like economics, mechanical engineering professors also command higher wages and have lower teaching loads than English faculty. As a result, the average difference in faculty pay across these two fields contributes substantially to the overall cost difference. Unlike economics, however, classes are only modestly larger in mechanical engineering than in English. Class size differences are not large enough to offset the higher salary and lower teaching load, thus mechanical engineering remains much more expensive than English.

Although each field is slightly different, a few general patterns emerge. Economics, political science, accounting, and business have high salaries which are offset by large classes, though not completely for the latter two fields. Engineering and nursing are more expensive than English due to higher salaries and lower teaching loads without commensurately larger classes. Workload and non-personnel expenses are important for some of the sciences with laboratory components, namely biology and chemistry, but otherwise explain relatively little of the observed cost differences.

More generally, instructional cost differences across fields can mostly be explained by large differences in class size across disciplines and, to a lesser extent, differences in average faculty pay. Teaching loads and other (non-personnel) expenditures explain relatively little. Further, some fields with highly paid faculty (like economics) fully offset salaries via large classes, generating costs that are comparable to English despite the higher pay.[31] One interpretation is that these patterns reflect important differences across fields in the production function of higher education – some fields are more amenable to the lecture-based format needed for large classes without a commensurate reduction in instructional quality. An alternative interpretation is that fields have different objectives dictating how they value instructional quality and other outputs. While possible, our within-institution analysis likely minimizes the role of differences in preferences or shared norms as an explanation. Within institutions, departments are overseen by common Provosts and Deans and also compete for students. Finally, it is possible that organizational and resource constraints dictate more cost comparability between fields typically housed in the same unit (e.g., economics and English) than those across units (e.g., economics and business).

V. Differences in Costs Over Time by Field of Study

Figure 5 plots field-specific trends in instructional costs since 2000 and net of institution-by-field fixed effects. We highlight three broad patterns. First, there are appreciable declines in costs in several STEM fields – mechanical engineering, chemistry, and physics – as well as in nursing. Second, a few fields experienced growth in costs during this time period, including

[31] It is worth recalling that these average pay differences already reflect instructor mix differences across fields, so they likely attenuate market-level pay differences across fields for instructors of a given rank.

English, education, accounting, communication, and fine arts. Finally, several fields experienced declines in expenditures that recovered by the end of the sample period. These striking differences across fields are masked when one looks at the aggregate spending trend shown in Figure 3. These patterns contrast with the broad spending declines in most fields in Florida, documented by Altonji and Zimmerman (2019), though they also found the largest drops in engineering and health.

Though several fields experience unusual time patterns, we focus on cross-field differences in the linear time trend over the whole sample period, estimated with:

$$ln(y_{cit}) = \varphi_{ci} + \beta_1 time + \gamma_c(time * \delta_c) + \varepsilon_{ci} \quad (2)$$

Here, y_{cit} is direct instructional expenditures per student credit hour in 2016 dollars for discipline *c* at institution *i* in year *t*. This model includes program fixed effects (field-by-institution, denoted φ_{ci}), to control for changes in the mix of academic programs, though these are not important in practice. The coefficients of interest are those on the field-specific linear time trends γ_c. They represent annualized changes in costs over the 17 year time period, relative to English, whose time trend is captured by β_1. To investigate mechanisms, we replace the outcome y_{cit} with a particular cost driver, such as the log of average class size for discipline *c* at institution *i* in year *t*. Program-level observations are weighted by the number of student credit hours multiplied by the inverse of the probability of being included in the sample (estimated at the institution-year level), though weighting does not substantively alter estimates.

Figure 6 presents estimates of average yearly changes in instructional costs and each of the cost drivers between 2000 and 2017. Costs grew for many fields, especially fine arts and history, while a subset of largely STEM-related fields saw real declines in expenditures.[32] Changes over time in costs for most fields are quite linear; however, our approach will be a relatively poorer approximation of the experiences of fields with non-linear cost changes over time, such as electrical engineering and computer science.[33] Focusing on one field across these panels allows one to tell a story about the drivers of field-specific cost changes over time. For example, in chemistry, the decline in costs over time of a bit over 1 percent per year is explained by an increase in average class size and a large increase in average faculty workload, which together more than compensate for the modest rise in faculty salaries.

Table 4 decomposes the field-specific linear growth rates shown in Figure 6 into the contribution made by changes in each of the four factors. Column 1 reports the average annual change in instructional costs for each of our 20 fields. The contribution to overall cost trend for each driver is reported in columns 2 to 5.[34] This trend analysis largely reinforces the conclusion of our cross-sectional analyses: across many fields, changes in faculty salaries and class sizes over time account for the bulk of changes in instructional costs between 2000 and 2017. For instance, mechanical engineering saw a 2.10 percent reduction in cost each year, which is more than fully explained by the large increase in class size. Costs for accounting rose by 0.64 percent annually, driven by faculty salary growth of 1.43 percent that outpaced increases in workload and class size. Some fields saw notable changes in faculty workload: education, English, and

[32] The steep decline observed for mechanical engineering is very robust: models excluding program fixed effects, not weighting, or using a balanced panel of programs appearing in all years all generate nearly identical trend estimates. Shifts in the level of instruction between lower, upper, and graduate training do not explain the trend.
[33] Appendix Figures A4 to A7 show the full trends over time in instructional costs and cost drivers by field, which illuminate patterns for fields with non-linear trends. For example, in computer science, a decline in average class size alongside an increase in average faculty salaries over the first half of our time period pushed costs up, while an increase in average class size and decline in salaries accounts for the drop in costs in more recent years.
[34] For example, electrical engineering costs decreased by 0.01 percent annually on average. Changes to salaries alone would have resulted in a 0.35 percent annual increase; reductions in workload would have resulted in a 0.19 percent increase. These are offset by reductions in cost due to increasing class sizes (-0.52 percent). Other expenses have a negligible decrease. Summing columns 2 to 5 equals the annual percentage change reported in column 1.

history studies all saw reductions in faculty workload over this period, which increased costs, while chemistry experienced a large increase. Only for nursing did changes in non-personnel expenditures increase costs, and for a few STEM fields there were appreciable declines in such expenditures – perhaps reflecting lower technology or lab-related costs.

VI. Deeper Investigation of Faculty Salary and Class Size

In this section, we undertake a deeper exploration of the two factors that account for the bulk of cost differences across fields: faculty salary and class size. Takeaways from cross-sectional and panel analyses are similar, and thus, for economy and ease of presentation, we focus here on the cross-sectional analysis.

At the department level, faculty salaries are a function of the mix of faculty (e.g., share tenure-track, share supplemental/adjunct) and average salary level conditional on type/rank. In our data, we cannot disaggregate compensation by faculty type; therefore we focus on faculty mix and its relationship to personnel expenditures.[35] Figure 7 displays cross-sectional differences in faculty mix by field.[36] There is quite a bit of variation in the share of tenure-track faculty by field, with only a little over 40 percent of nursing faculty on the tenure track but nearly three-quarters of mechanical and electrical engineering faculty in tenure-track roles. English, communications, and math also have relatively low shares of tenure-track faculty. Thus greater use of tenure-track faculty, which are more expensive, is one explanation for higher personnel costs in engineering, economics, and the sciences. The greater use of such faculty by some fields could reflect a number of things, including how different faculty types enter into the production

[35] This means that we cannot formally integrate our disaggregated explorations of this driver (nor the next) into the accounting identity that guided our decomposition analyses.

[36] "Supplemental faculty" refers to instructors paid for their teaching from a temporary pool of funds whose appointments are temporary in nature with no expectation of recurring. "Other regular" faculty may engage in research and service in addition to teaching and have a relationship to the institution that presumes a recurring appointment. More detailed definitions can be found on the Delaware Cost Study website: https://ire.udel.edu/definitions/

function or differences in the availability of non-tenure-track instructors to draw on to teach.[37] Appendix Figure A8 documents field-specific trends over time in faculty mix. Between 2000 and 2017, the majority of fields experienced a clear decline in the share of tenure-track faculty alongside offsetting increases in shares of contingent faculty. However, the swiftness of the decline differed by field.[38]

We now turn to the second key cost driver, class size. Differences in class size are a function of the mix of course types offered (i.e., lower-level undergraduate, upper-level undergraduate, and graduate) as well as the average class size conditional on type of course. Figure 8 shows substantial differences in the mix of course types offered, with relatively fewer lower-division courses in professional fields like nursing, education, and business, and many lower-division courses in the sciences (physics and chemistry) and mathematics. Fields with relatively little undergraduate instruction, like engineering and nursing, tend to be more expensive. Appendix Figure A9 plots trends in average class size by course type for each field (Panel A) as well as trends in the mix of course types by field (Panel B). Between 2000 and 2018, average class size conditional on level of course remained fairly steady for most fields in the social sciences and humanities (with the exception of a recent decline in average undergraduate class sizes for history); however, many STEM fields experienced marked increases in undergraduate class sizes over this period, including engineering, biology, and

[37] The share of tenure-track faculty will also relate to the program's desire for research productivity, which we do not examine.

[38] This drop was especially pronounced for nursing, where by 2017 the typical nursing program had roughly equal shares of tenure-track and "other" faculty and a relatively large share of "supplemental" faculty. This change in faculty rank mix is reflected in the salary trend for nursing, where we see a modest decline. For example, if tenure-track faculty in nursing became more expensive over this time, programs may have chosen less expensive faculty types to combat cost growth and satisfy their budget constraints. The shift in nursing faculty may also reflect changes to nursing instruction itself, toward RN-to-BSN programs with greater reliance on contingent faculty.

chemistry.[39] While increases in class size may be one way to offset cost pressures from other drivers, the effects of larger classes on students' performance and attainment in STEM fields is unclear and may depend on the use of other pedagogical features, such as "highly structured course designs" (Haak et al., 2011).

VII. Is Online Instruction Cost-Saving?

Online instruction has commanded sustained interest from policymakers and institutional leaders as a possible strategy for counteracting price growth (e.g., Deming, Goldin, Katz, &Yuchtman, 2015; Bowen, 2013) and expanding postsecondary access (Goodman, Melkers, & Pallais, 2019). Using a new online survey component that was added to the Delaware Cost Study in 2015,[40] we investigate the adoption and expansion of online instruction and its association with costs. Figure 9 reports the share of total credits delivered online by discipline, for undergraduate and graduate instruction. There is substantial variation in the prevalence of online instruction, ranging from essentially zero (undergraduate engineering) to as much as a third of all credits (graduate nursing).

Table 5 shows descriptive statistics for programs divided into five groups: no online enrollment, and (conditional on any online instruction) the quartiles of online shares. In the 20 disciplines we study, 51 percent of programs have no online enrollment. Our sample contains 17 fully online programs, some of them for multiple years, and the average share of online credits is

[39] The increase in average class size for nursing was partially driven by a decrease in the share of credits that were lower-division and an increase in the share of graduate-level credit hours. However, average class sizes for all types of nursing courses, undergraduate and graduate, also trended upward over time. In contrast, the uptick in overall average class size for mechanical engineering documented earlier was driven by an increase in class sizes among all levels of undergraduate courses, rather than by a large shift in the mix of courses taught.

[40] A wide range of programs and institutions responded to the new online survey component. Indeed, over 95 percent of the 2,158 programs across 173 institutions and 20 fields of study that completed the main survey in 2015 also completed the new online section. The remaining 107 programs come from 11 institutions, with 9 of those not completing the online portion for any of their programs in our sample. Non-respondents were more likely to be private institutions with moderate levels of research activity. All programs in our main sample completed this portion of the survey in 2016 and 2017.

6 percent. The relevant range of "intensity" observed in our sample is modest, which ought to temper any proclivity to overgeneralize these findings. Online offerings, as well as exclusively online programs, are more prevalent in graduate education. Private institutions, those with larger shares of undergraduate credits, and those with larger shares of tenure-track faculty all have less online enrollment.

To better understand the relationship between online offerings and costs, we present estimates from regression models in Table 6. We associate within-program variation over time in the adoption (Panel A) and intensity (Panel B) of online offerings with changes in instructional costs. That is, all models include program (i.e., department-by-institution) and year fixed effects to address potential selection bias since departments choose whether to offer online courses. Columns 2 and 4 permit associations to differ for undergraduate and graduate instruction.

We find a negligible association between online credits and instructional costs; coefficients are close to zero, insignificant, and inconsistent in sign. The estimates from column 3 imply that adoption of any online coursework is associated with a 0.4 percent cost increase and that a 10 percentage point increase in online intensity is associated with a 1.4 percent cost decrease, though neither of these is significant. We view these estimates as small, especially given the attention paid to the cost-saving potential of online instruction.

The reduction in costs due to online coursework is hypothesized to operate through reduced labor costs via bigger classes and less face-to-face instruction (Deming et al., 2015; Bowen, 2012). However, there is debate about the appropriate size for online courses relative to traditional in-person ones, with some institutions actually imposing lower enrollment caps for online courses (D'Orio, 2017). Columns 5 to 8 report how the individual cost drivers correlate with online share. We see some evidence that an increase in the intensity of undergraduate online coursework is related to lower salary costs.[41] Though statistically insignificant, estimates for the other drivers suggest that any short-run cost savings on salaries are offset by smaller classes and an uptick in non-personnel expenditures. Two caveats are in order. First, this analysis uses a short panel, and thus cannot illuminate long-run cost changes that might emerge from sustained adoption of online instruction.[42] Second, we do not observe costs shared across departments such as capital costs or costs for technology support.

The returns to the adoption of new technology such as online courses will depend on a field's production function, and how online education alters it; moving to online instruction may decrease quality-adjusted output for some fields more than others. Indeed, recent evidence suggests that online instruction, even forms that blend face-to-face and virtual instruction, may harm student performance, especially for lower-achieving students (Bettinger & Loeb, 2017; Dynarski, 2018; Kozakowski, 2019). Some fields may find online education a more useful tool than others in lowering costs without compromising quality. Better understanding this element of fields' production functions is a productive path for future research.

VIII. Conclusions

In this paper we use detailed data on costs, outputs, and factors of production to provide a comprehensive descriptive analysis of field-level instructional costs in higher education. This analysis reveals appreciable variation in the cost of delivering a unit of teaching across fields:

[41] Recall that this outcome reflects both the mix of faculty types (e.g., tenure-track and adjunct) as well as average salaries conditional on type.

[42] In a complementary analysis using a longer time horizon, we find that online instruction is associated with a modest cost reduction for undergraduate courses. This modest decline is largely driven by undergraduate programs that are substantially online and we find no such cost savings for graduate coursework. These "long-run" estimates come from a model in which we include log instructional cost from an early period in our sample (early 2000s) as a control variable in place of program fixed effects. This is similar to a long differences model assuming online instruction is essentially zero in the early 2000s, though we do not impose that the coefficient on lagged cost is one. However, the long-run setup is unable to exploit within-program variation and thus findings may be partially driven by selection. Results available from authors upon request.

relative to English, costs range from 92 percent higher for electrical engineering to 25 percent lower for math. This variation in costs is a function of large differences in class size and, to a lesser extent, differences in average faculty pay. We observe different stories across fields in terms of the trade-offs implied by the cost drivers. Some fields, like economics, offset high wages with large classes, resulting in costs that are comparable to English despite higher faculty pay. Other fields, such as mechanical engineering and computer science, do not offset high faculty pay with large classes, resulting in costs that are much greater than English. Still others, like physics, partially offset higher faculty salaries with heavier faculty workloads, resulting in costs that are moderately higher than English.

Over the past 17 years, average instructional costs per credit hour have increased only modestly. However, this relatively flat trend in average costs obscures variation in such cost trends by field of study. Some STEM fields experienced steep declines in spending over this time period as classes became larger and faculty workloads increased. Other fields like nursing also saw declining costs that reflect a shift in the composition of faculty, with greater reliance on non-tenure track staff. Yet other fields, like business and accounting, have experienced escalating costs driven by rapid growth in faculty salaries. For all its promise, online education, arguably the highest profile change to the delivery of higher education over this time period, is not associated with cost savings.

The cross-sectional findings highlight the fact that costs associated with instructional activity vary greatly across disciplines. Analyses of costs at the institution level mask this heterogeneity. Variation in costs by discipline has important implications for institutional leaders facing decisions such as differential tuition pricing or the appropriate level of centralization for managing academic units and budgets (e.g., the adoption of responsibility centered management). Cost differences by discipline also have implications for institutional or governmental efforts to encourage student enrollments in certain high-cost disciplines (e.g., the numerous initiatives aimed at increasing attainment in STEM), and for the distribution of state appropriations to public universities. The panel analysis suggests ways in which universities and departments may have sought to manage costs. Institutions have little control over the prevailing market wages for faculty, but changes in faculty workload, class size, and mix of course types (i.e., undergraduate versus graduate, and in-person versus online) across disciplines show some of the ways that costs might be kept in check. However, changes along these margins are also likely to shape other departmental outputs, such as research productivity and the capacity for public service. Thus, changes aimed at reducing instructional costs must balance potential effects on other valued outputs of academic departments.

Many of our findings highlight the fact that the production function in higher education is likely to differ meaningfully by field. Thus, these results trumpet the need for additional research that sheds light on the effects of inputs on field-specific outcomes, including measures of quality such as student performance and success after college completion. For example, perhaps the adoption of online instruction reduces average instructional costs without impinging on quality in mathematics, but a similar reliance on online education in chemistry reduces quality. It is imperative to consider the effect that resource allocation decisions have on learning, instructional quality, and student outcomes and how this differs by field – especially in light of recent evidence that ties increases in spending to higher rates of degree completion (Deming & Walters, 2017). This next step would allow policymakers and institutional leaders to use the findings related to discipline-specific cost drivers from this paper in a manner most likely to reduce costs while upholding the quality of postsecondary educational delivery.

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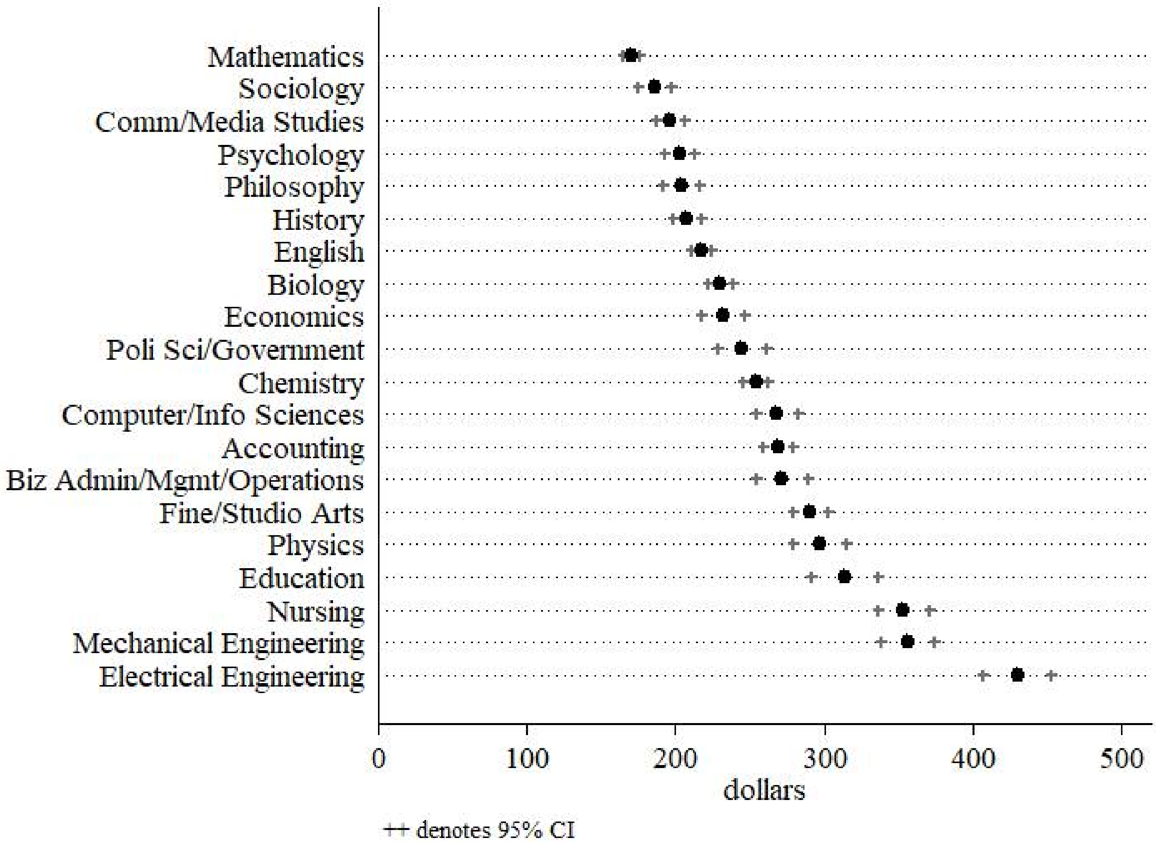
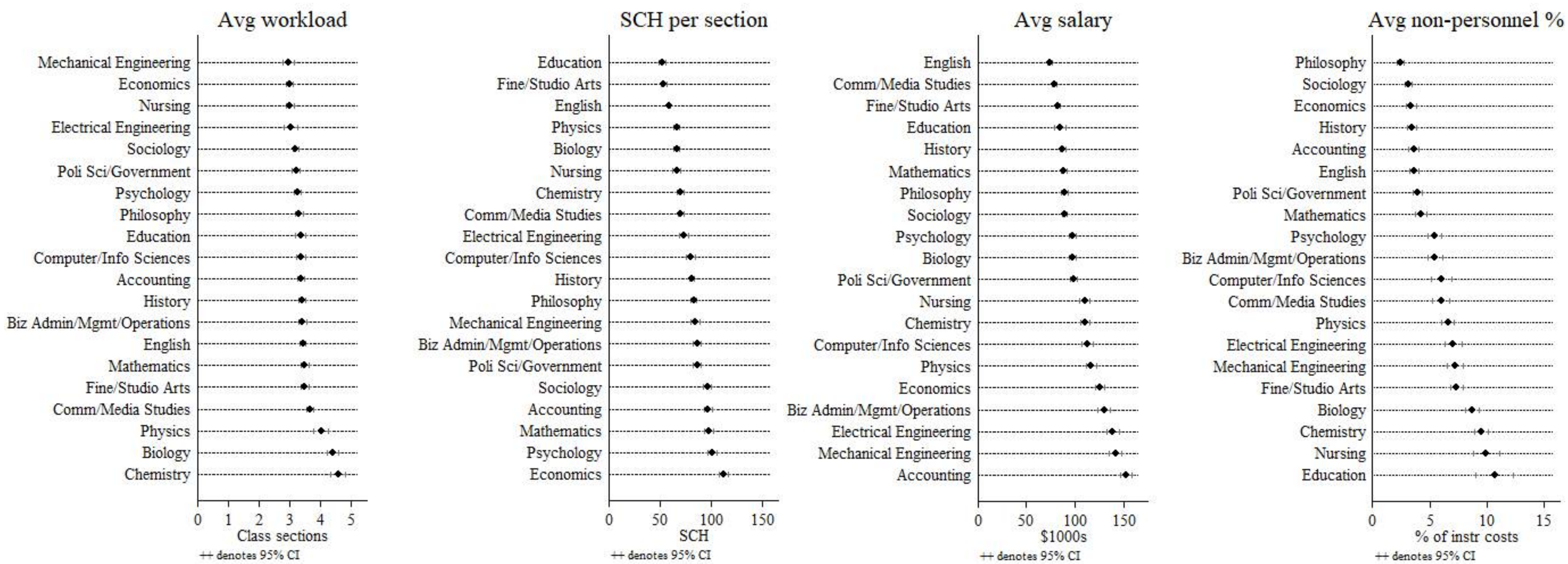
Figure 1. Average Instructional Cost by Field



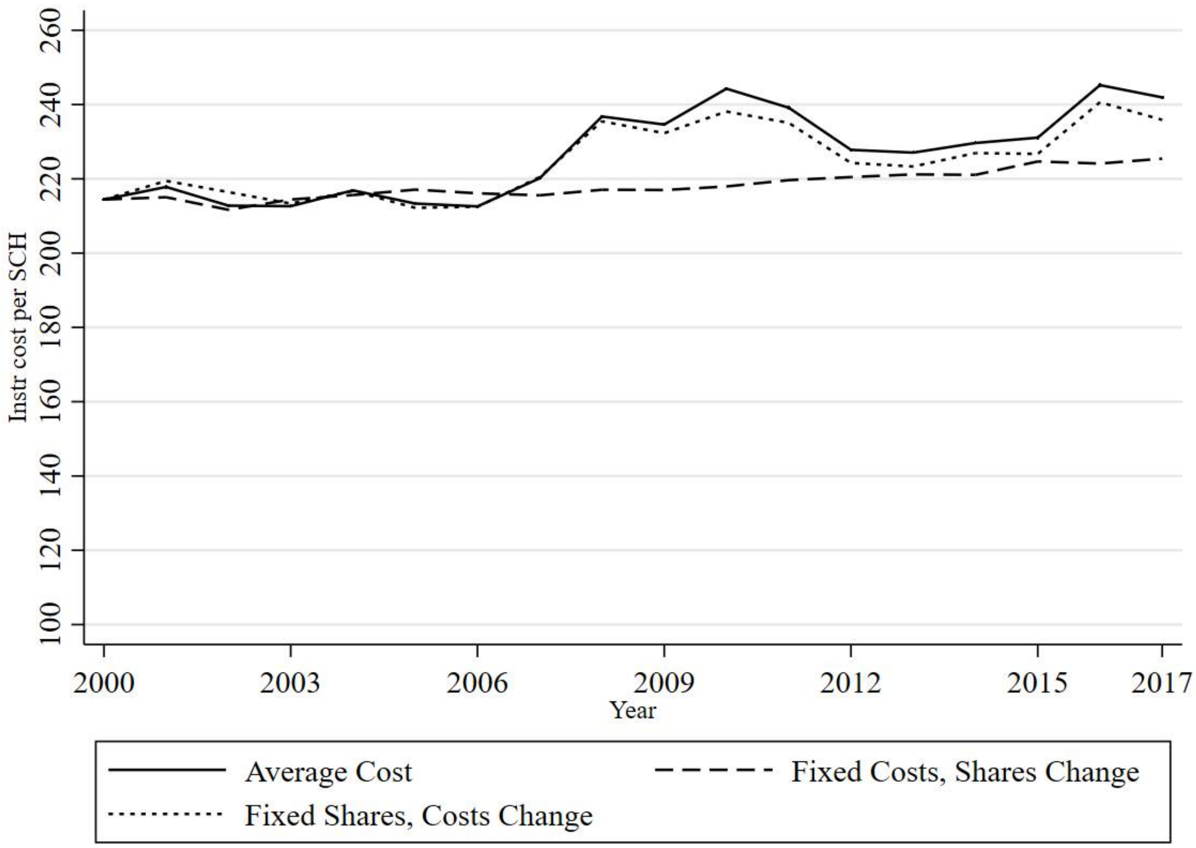
Notes: Sample includes public and private institutions participating in the Delaware Cost Study between 2015 and 2017. Only departments in the 20 fields listed in Appendix Table A2 are included. A small number of observations with missing or outlier data are excluded. Program-level observations are weighted by number of student credit hours multiplied by the inverse of the probability of being included in the sample (estimated at the institution-year level). Costs are in 2016 dollars.

Figure 2. Differences in Cost Drivers Across Fields



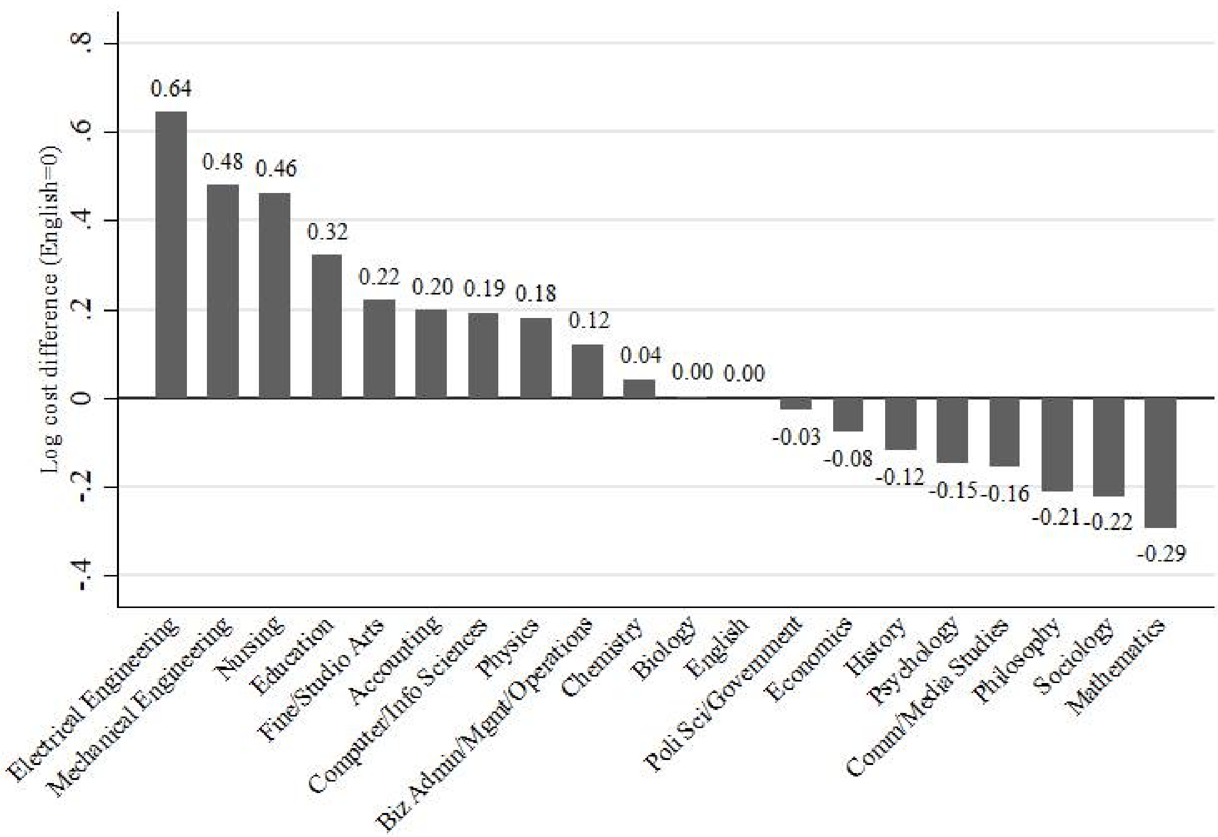
Notes: Sample includes public and private institutions participating in the Delaware Cost Study between 2015 and 2017. Only departments in the 20 fields listed in Appendix Table A2 are included. A small number of observations with missing or outlier data are excluded. Program-level observations are weighted by number of student credit hours multiplied by the inverse of the probability of being included in the sample (estimated at the institution-year level). Costs are in 2016 dollars. Workload is the number of organized class sections divided by the number FTE faculty, SCH per section is the total number of student credit hours (SCH) divided by the number of organized class sections, average salary is the total personnel costs divided by the number of FTE faculty, and average non-personnel percentage is the total non-personnel costs divided by the total personnel costs.

Figure 3. Average Instructional Cost per Student Credit Hour, Actual and Counterfactual



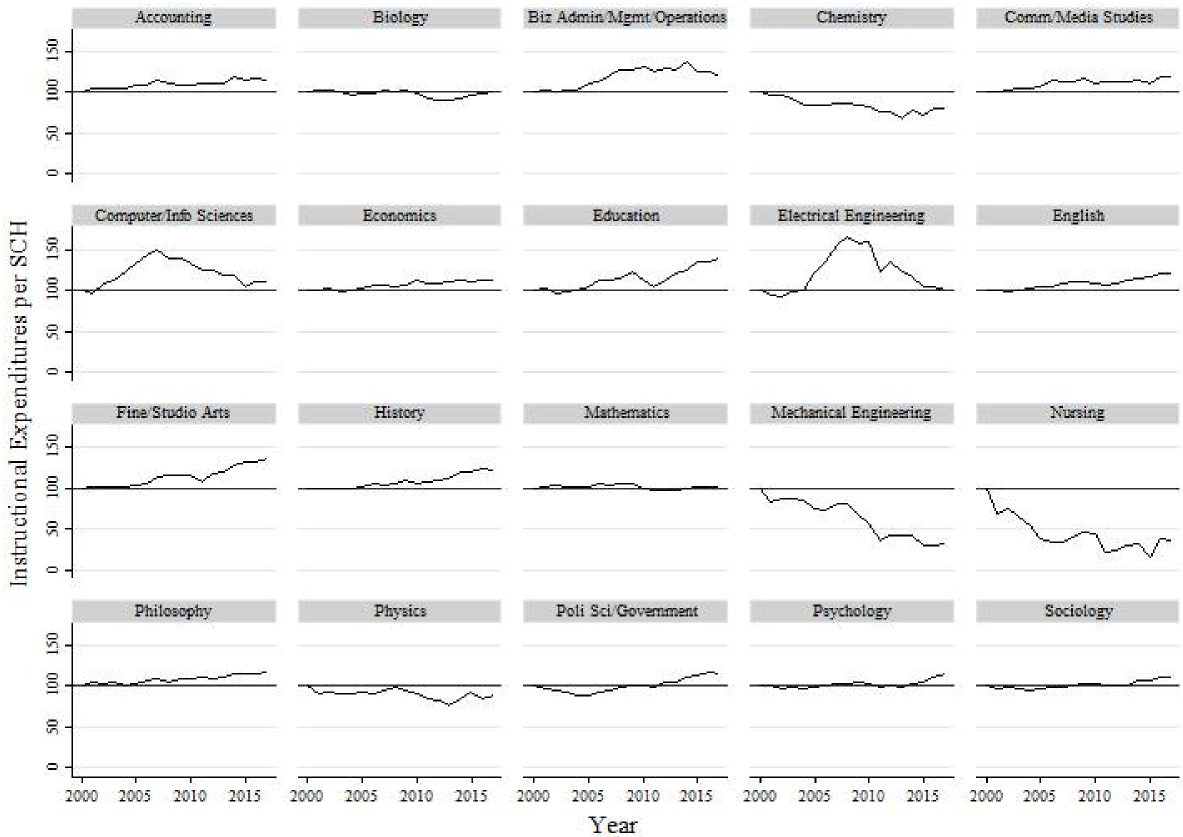
Notes: Cost refers to direct instructional expenditures per student credit hour. Sample includes public and private institutions participating in the Delaware Cost Study between 2000 and 2017. Only departments in the 20 fields listed in Appendix Table A2 are included. A small number of observations with missing or outlier data are excluded. Program-level observations are weighted by the inverse of the probability of being included in the sample (estimated at the institution-year level). The "Fixed Costs, Shares Change" counterfactual trend is estimated by fixing instructional cost per SCH in each field at their 2000 values and letting shares of total credits by field adjust as they actually did. The "Fixed Shares, Costs Change" counterfactual trend is estimated by fixing the shares of total credits at their 2000 values, but letting instructional cost per SCH in each field evolve as they actually did. Costs are in 2016 dollars.

Figure 4. Baseline Cross-Field Log Cost Differences, relative to English



Notes: Each column reports the difference in log of direct instructional cost per SCH between the reported field and English, after controlling for institution and year fixed effects. Positive numbers indicate the field is more expensive than English. Sample includes public and private institutions participating in the Delaware Cost Study between 2015 and 2017. Only departments in the 20 fields listed in Appendix Table A2 are included. A small number of observations with missing or outlier data are excluded. Program-level observations are weighted by number of student credit hours multiplied by the inverse of the probability of being included in the sample (estimated at the institution-year level). Costs are in 2016 dollars.

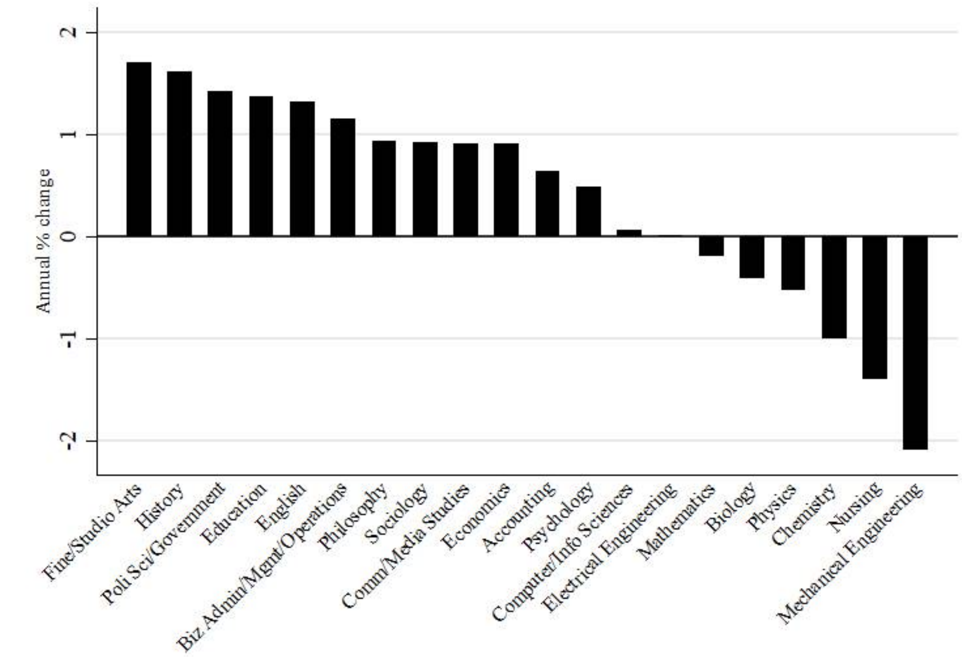
Figure 5. Direct Instructional Expenditure per SCH Over Time, by CIP4 (2000 = 100), 2000-2017



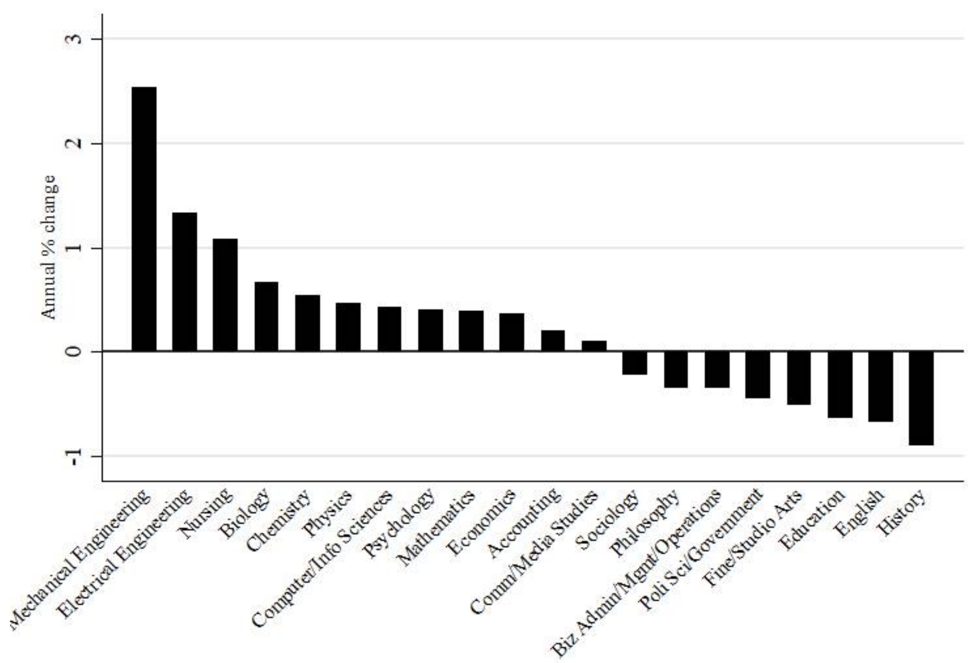
Notes: Sample includes public and private institutions participating in the Delaware Cost Study between 2000 and 2017. Only departments in the 20 fields listed in Appendix Table A2 are included. A small number of observations with missing or outlier data are excluded. Program-level observations are weighted by number of student credit hours multiplied by the inverse of the probability of being included in the sample (estimated at the institution-year level). Trends are normalized to the year 2000 and net of institution-by-field (i.e., program) fixed effects.

Figure 6. Average Annual Percentage Change in Costs and Cost Drivers by Field

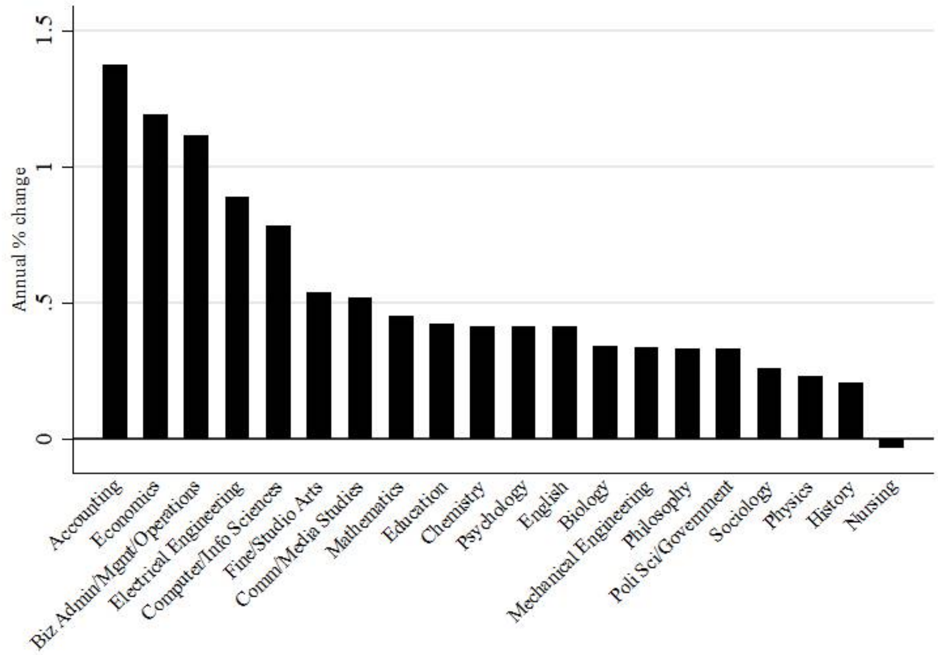
A. Instructional Expenditures



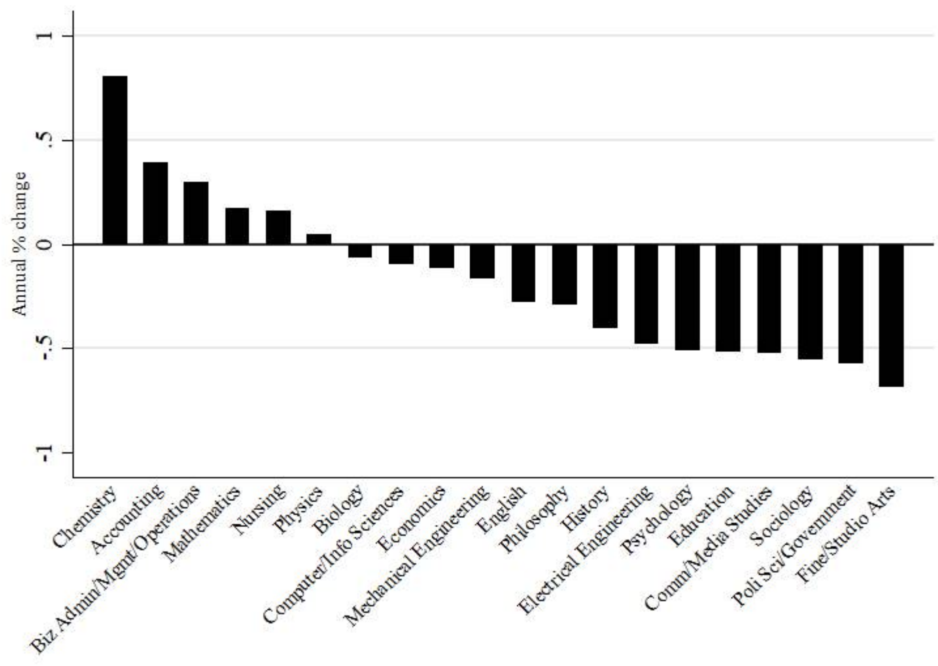
B. Class Size



C. Faculty Salaries

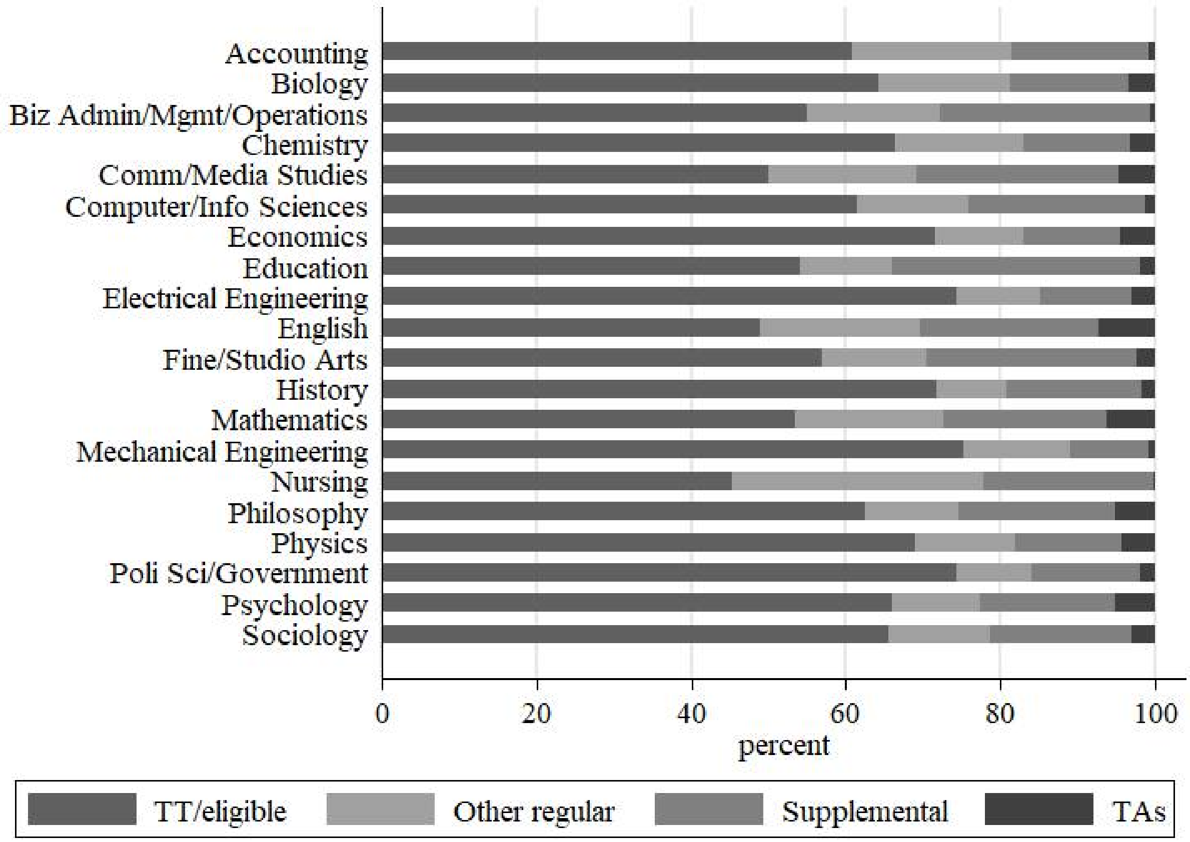


D. Faculty Workload



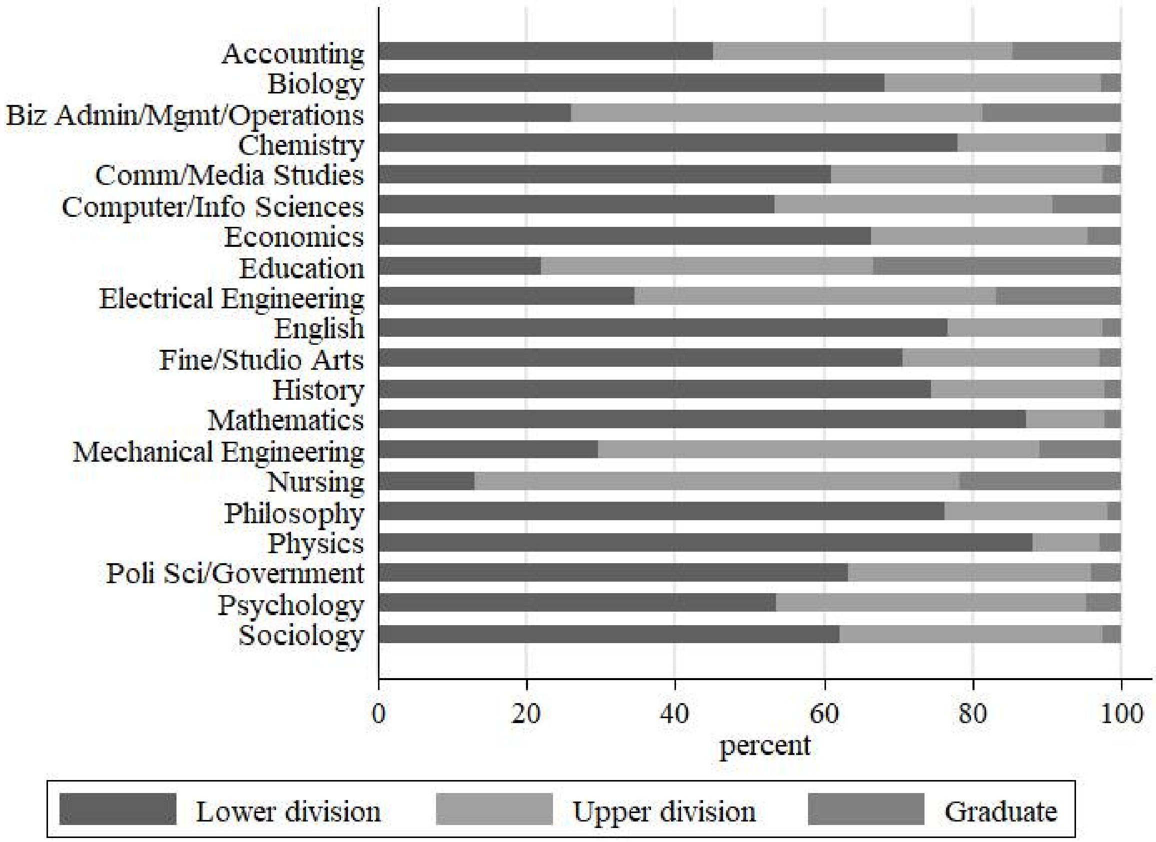
Notes: Bars represent annualized rate of change between 2000 and 2017. Estimates include program fixed-effects. Dollar figures expressed in 2016 dollars. Sample includes public and private institutions participating in the Delaware Cost Study between 2000 and 2017. Only departments in the 20 fields listed in Appendix Table A2 are included. A small number of observations with missing or outlier data are excluded. Program-level observations are weighted by number of student credit hours multiplied by the inverse of the probability of being included in the sample (estimated at the institution-year level).

Figure 7. Cross-Sectional Differences in Faculty Mix by Field, 2015-2017



Notes: Bars report proportion of faculty FTE in each rank. Sample includes public and private institutions participating in the Delaware Cost Study between 2015 and 2017. Only departments in the 20 fields listed in Appendix Table A2 are included. A small number of observations with missing or outlier data are excluded. Program-level observations are weighted by number of student credit hours multiplied by the inverse of the probability of being included in the sample (estimated at the institution-year level). "Supplemental faculty" are instructors paid for their teaching from a temporary pool of funds whose appointments are temporary in nature with no expectation of recurring. "Other regular" faculty may engage in research and service in addition to teaching and have a relationship to the institution that presumes a recurring appointment.

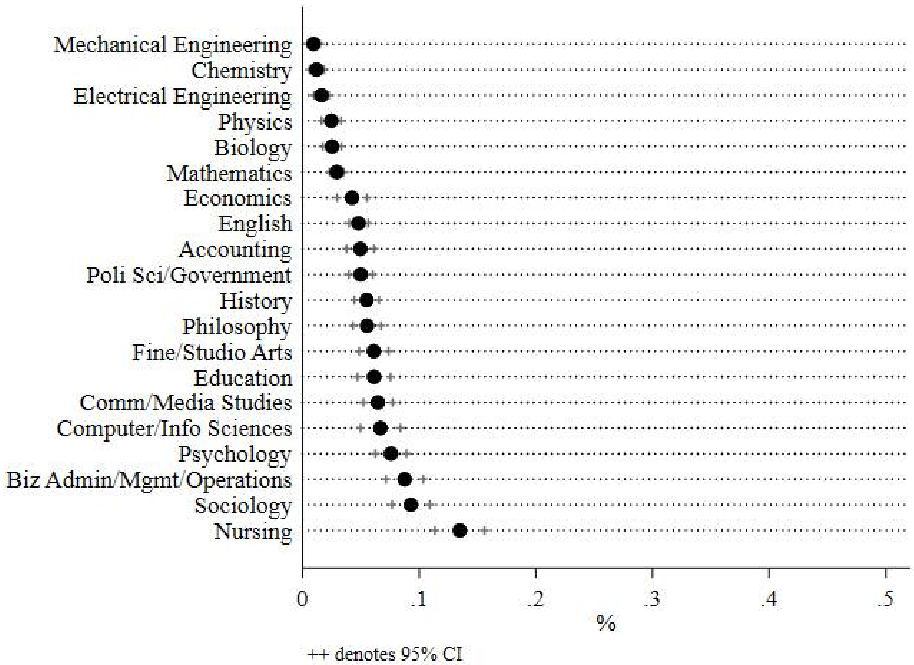
Figure 8. Cross-Sectional Differences in Credit-Level Mix by Field, 2015-2017



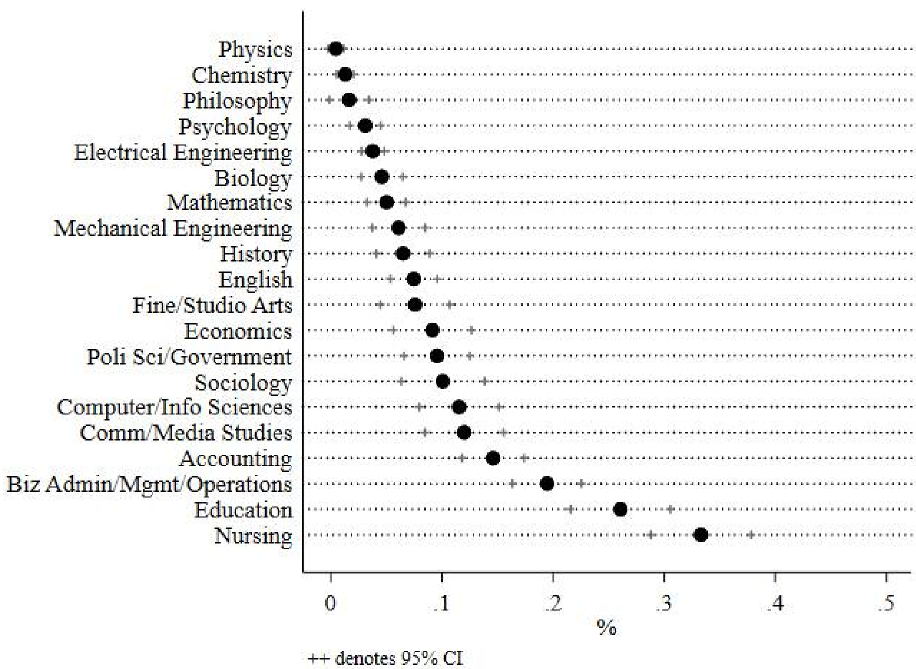
Notes: Bars report proportion of total student credit hours in each division. Sample includes public and private institutions participating in the Delaware Cost Study between 2015 and 2017. Only departments in the 20 fields listed in Appendix Table A2 are included. A small number of observations with missing or outlier data are excluded. Program-level observations are weighted by number of student credit hours multiplied by the inverse of the probability of being included in the sample (estimated at the institution-year level).

Figure 9. Share of Total Instruction Delivered Online by Field

A. Undergraduate



B. Graduate



Notes: Sample includes public and private institutions participating in the Delaware Cost Study in 2015 and 2017. Only departments in the 20 fields listed in Appendix Table A2 are included. A small number of observations with missing or outlier data are excluded. Program-level observations are weighted by number of student credit hours multiplied by the inverse of the probability of being included in the sample (estimated at the institution-year level).

Table 1. Summary Statistics for Full Sample

	All		Research - High		Research - Moderate		Masters		Baccalaureate	
	mean	sd	mean	sd	mean	sd	mean	sd	mean	sd
Instructional Spending per SCH	$228	$125	$260	$150	$237	$110	$200	$94	$214	$114
Instructional Personnel Spending per SCH	$212	$110	$239	$130	$212	$97	$190	$88	$199	$99
Total Spending per SCH	$268	$214	$353	$289	$240	$126	$207	$115	$216	$121
Public Institutions	67%		90%		43%		64%		16%	
Total Degrees Awarded	121		180		153		81		27	
BA share	83%		75%		76%		87%		99%	
MA share	15%		18%		22%		13%		1%	
Professional share	0%		0%		0%		0%		0%	
PhD share	3%		6%		1%		0%		0%	
Fall Semester SCH by All Faculty	8,084	7,410	12,489	8,368	8,654	6,756	5,360	4,575	2,037	1,960
Undergraduate share	93%		91%		89%		94%		99%	
Fall Semester Total FTE Faculty	33	32	51	35	37	33	22	22	9	8
Fall Semester Instructional FTE Faculty	33	31	50	34	37	33	22	22	9	8
Tenured/tenure-track share	62%		61%		62%		63%		67%	
Fall Semester Organized Class Sections	104	98	146	110	112	94	79	81	37	32
Undergraduate share	86%		79%		83%		90%		99%	
Graduate share	14%		21%		17%		10%		1%	
Estimated Class Size	34	24	44	30	32	21	27	13	22	8
Undergraduate Class Size	39	36	55	50	35	22	29	16	22	8
Graduate Class Size	12	9	12	8	15	15	12	9	11	5
Instructional Faculty Course Load	3.5	1.8	3.1	2.5	3.3	1.3	3.8	1.2	4.1	1.5
N (institution-program-year)	43,819		18,147		4,077		18,072		3,523	
Weighted by IPW * SCH	100%		38%		10%		41%		11%	

Notes: Sample includes public and private institutions participating in the Delaware Cost Study between 2000 and 2017. Only departments in the 20 fields listed in Appendix Table A2 are included. A small number of observations with missing or outlier data are excluded. Program-level observations are weighted by number of student credit hours multiplied by the inverse of the probability of being included in the sample (estimated at the institution-year level). Costs are in 2016 dollars. SCH = Student Credit Hour; FTE = Full Time Equivalent

Table 2. Characteristics of Fields, by Cost

			Organizational structure and revenue sources				
Field	Log cost difference	Median earnings years 11-15 ($1000, relative to English)	Typically separate school from Arts & Sciences?	% of universities with differential pricing	Differential in TX funding formula	Tier in NC funding formula	Annual growth rate of credit hours, 2000 to 2017, %
Electrical Engineering	0.64	42.0	Yes	30%	Yes	IV	2.1
Mechanical Engineering	0.48	38.7	Yes	30%	Yes	IV	4.9
Nursing	0.46	12.4	Yes	16%	Yes	IV	5.4
Education	0.32	-5.4	Yes	11%		II, III	-1.4
Fine/Studio Arts	0.22	-7.7	Yes	8%	Yes	III	-0.1
Accounting	0.20	17.6	Yes	32%		II	1.4
Computer/Info Sciences	0.19	30.3	Varies	8%	Yes	III	0.7
Physics	0.18	31.9		11%	Yes	III	2.0
Biz Admin/Mgmt/Operations	0.12	11.1	Yes	32%		II	1.0
Chemistry	0.04	16.4		11%	Yes	III	3.0
Biology	0.00	8.8		11%	Yes	III	2.7
English	ref	0.0		ref		I	-0.3
Poli Sci/Government	-0.03	15.5		0%		I	0.1
Economics	-0.08	32.2		0%		I	0.7
History	-0.12	6.5		0%		I	-0.4
Psychology	-0.15	-1.0		0%		I	1.3
Comm/Media Studies	-0.16	7.9	Varies	6%		I	1.3
Philosophy	-0.21	1.4		0%		I	0.6
Sociology	-0.22	1.8		0%		I	0.2
Mathematics	-0.29	21.4		0%		I	1.5

Sources: Median earnings come from Hershbein and Kearney (2012) analysis of the ACS, expressed relative to median earnings for English ($46,000). Separate school refers to whether the field is typically housed in a separate school or college from English, which is traditionally in a School of Arts & Science. Funding formula difference in Texas refers to difference for upper division courses that is different than that for upper division English courses. Negligible differences for education are ignored. Funding formula in North Carolina splits fields into four tiers. Differential pricing information comes from Nelson (2008) survey of 165 public research universities. Field-specific linear annual growth rate of credit hours includes undergrad and graduate credits and is calculated from regression model that includes program fixed effects.

Table 3. What Drives Cost Differences by Field? Cross-Sectional Decomposition

		Contribution to Difference			
	Overall Difference in Costs	Salary	Workload	Class size	Other, Non-Personnel Expenses
Field of Study	(1)	(2)	(3)	(4)	(5)
Electrical Engineering	0.64	0.57	0.02	0.02	0.04
Mechanical Engineering	0.48	0.54	0.08	-0.18	0.04
Nursing	0.46	0.31	0.13	-0.05	0.07
Education	0.32	0.08	0.03	0.14	0.07
Fine/Studio Arts	0.22	0.06	-0.04	0.16	0.04
Accounting	0.20	0.61	-0.05	-0.36	0.00
Computer/Info Sciences	0.19	0.35	-0.04	-0.13	0.02
Physics	0.18	0.34	-0.16	-0.03	0.03
Biz Admin/Mgmt/Operations	0.12	0.43	-0.04	-0.29	0.02
Chemistry	0.04	0.29	-0.25	-0.06	0.06
Biology	0.00	0.22	-0.20	-0.07	0.05
English	(reference)				
Poli Sci/Government	-0.03	0.19	0.04	-0.26	0.01
Economics	-0.08	0.40	0.03	-0.51	0.00
History	-0.12	0.11	0.02	-0.26	0.00
Psychology	-0.15	0.21	0.05	-0.42	0.02
Comm/Media Studies	-0.16	0.04	-0.09	-0.13	0.02
Philosophy	-0.21	0.09	-0.01	-0.28	0.00
Sociology	-0.22	0.14	0.04	-0.40	0.00
Mathematics	-0.29	0.11	-0.04	-0.36	0.01

Notes: Difference in cost measured as log difference from English. We hold three of the cost drivers at the values for English and allow the focal cost driver to take the value for the specific field. All models are weighted by total student credit hours*IPW. All underlying cost values are in 2016 dollars.

Table 4. What Drives Differences in Field-Specific Cost Trends? Longitudinal Decomposition

		Contribution to % Change in Costs			
	Annual % Change in Costs	Salary	Workload	Class size	Other Expenses
Field of Study	(1)	(2)	(3)	(4)	(5)
Fine/Studio Arts	1.70	0.56	0.72	0.54	-0.11
History	1.61	0.23	0.45	1.01	-0.08
Poli Sci/Government	1.42	0.36	0.63	0.49	-0.07
Education	1.38	0.51	0.62	0.76	-0.50
English	1.32	0.44	0.30	0.71	-0.13
Biz Admin/Mgmt/Operations	1.16	1.08	-0.29	0.34	0.02
Philosophy	0.94	0.38	0.33	0.39	-0.16
Sociology	0.93	0.26	0.56	0.23	-0.12
Comm/Media Studies	0.91	0.60	0.60	-0.12	-0.17
Economics	0.90	1.31	0.13	-0.41	-0.13
Accounting	0.64	1.43	-0.41	-0.21	-0.17
Psychology	0.48	0.52	0.64	-0.52	-0.16
Computer/Info Sciences	0.06	0.41	0.05	-0.22	-0.18
Electrical Engineering	-0.01	0.35	0.19	-0.52	-0.02
Mathematics	-0.20	0.45	-0.17	-0.39	-0.09
Biology	-0.41	0.32	0.06	-0.62	-0.17
Physics	-0.53	0.27	-0.06	-0.56	-0.19
Chemistry	-1.00	0.39	-0.75	-0.51	-0.13
Nursing	-1.40	-0.04	-0.19	-1.27	0.10
Mechanical Engineering	-2.10	0.34	0.17	-2.56	-0.05

Notes: Annual percent change in cost measured between 2000 and 2017, inclusive of program fixed effects. We calculate annual percent change for each cost driver and normalize to annual change in instructional costs to estimate contribution of individual drivers. Columns (2) to (5) thus sum to the total for column (1). All calculations are weighted by total student credit hours*IPW.

Table 5. Summary Statistics for Online Instruction Sample

	No Online Enrollment		1st Quartile Online Enrollment		2nd Quartile Online Enrollment		3rd Quartile Online Enrollment		4th Quartile Online Enrollment	
	mean	sd	mean	sd	mean	sd	mean	sd	mean	sd
Instructional Spending per SCH	$254	$122	$234	$132	$231	$117	$217	$115	$219	$129
Instructional Personnel Spending per SCH	$239	$112	$219	$117	$218	$108	$203	$109	$203	$116
Total Spending per SCH	$293	$194	$289	$231	$268	$185	$238	$143	$242	$172
Public Institutions	53%		83%		79%		83%		81%	
Total Online Credit Share	0.00	0.00	0.01	0.01	0.05	0.01	0.11	0.03	0.33	0.19
Undergraduate share online	0.00	0.00	0.01	0.01	0.05	0.03	0.10	0.04	0.28	0.20
Graduate share online	0.00	0.00	0.05	0.14	0.07	0.16	0.14	0.24	0.33	0.36
Total Degrees Awarded	90		128		136		178		319	
BA share	86%		79%		79%		81%		76%	
MA share	11%		17%		18%		17%		22%	
Professional share	0%		0%		0%		0%		0%	
PhD share	3%		4%		3%		2%		1%	
Fall Semester SCH by All Faculty	5,891	5,847	11,294	8,205	9,762	7,206	10,367	8,659	10,188	11,068
Undergraduate share	95%		93%		92%		91%		84%	
Fall Semester Total FTE Faculty	25	22	44	29	40	30	41	33	44	58
Fall Semester Instructional FTE Faculty	24	22	43	28	39	29	40	32	43	58
Tenured/tenure-track share	66%		56%		58%		56%		52%	
Fall Semester Organized Class Sections	77	66	138	90	124	96	129	105	136	221
Undergraduate share	89%		84%		85%		85%		77%	
Graduate share	11%		15%		15%		15%		23%	
Estimated Class Size	34	22	38	22	35	26	32	19	31	18
Undergraduate Class Size	39	29	46	33	37	20	35	16	35	24
Graduate Class Size	12	7	12	6	12	7	11	6	12	6
Instructional Faculty Course Load	3.6	1.7	3.4	1.2	3.4	1.2	3.4	1.2	3.3	1.2
N (institution-program-year)	3,382		822		821		822		821	
Weighted by IPW * SCH	51%		12%		12%		12%		12%	

Notes: Sample includes public and private institutions participating in the online component of the Delaware Cost Study between 2015 and 2017. Observations are weighted by the inverse of the likelihood that a given institution participates in the Delaware Cost Study multiplied by a measure of the program's size (i.e., total fall student credit hours). Costs are in 2016 dollars. SCH = Student Credit Hour; FTE = Full Time Equivalent

Table 6. Online Courses and Instructional Costs

	Log instructional cost per student credit hour				Salary	Workload	Class Size	Non personnel
Independent variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
A. Presence of Online Instruction								
Any online credits in year	-0.007		0.004					
	(0.025)		(0.020)					
Any online UG credits in year		-0.011		0.003	1.109	0.0639	0.0348	-0.142
		(0.016)		(0.018)	(1.935)	(0.0711)	(1.176)	(0.404)
Any online GR credits in year		-0.018		-0.030	2.095	0.0102	1.246	-0.592
		(0.022)		(0.038)	(3.148)	(0.0778)	(2.027)	(0.704)
B. Intensity of Online Instruction								
Online as a share of total credits			-0.144					
			(0.148)					
Online share of undergraduate credits				-0.193	-20.38*	0.0615	-6.429	2.133
				(0.151)	(10.11)	(0.286)	(5.794)	(2.177)
Online share of graduate credits				0.059	-3.609	-0.0889	-2.262	0.624
				(0.079)	(6.505)	(0.177)	(3.653)	(1.291)
Outcome mean					99.73	3.51	79.34	5.80
Observations	6,668	6,668	6,668	6,668	6,668	6,668	6,668	6,668
R-squared	0.940	0.940	0.940	0.940	0.921	0.901	0.959	0.878

Notes: All models include program (i.e., institution-by-field) and year fixed effects. When data are missing, for example, because a program did not report or does not have graduate online instruction, we include an indicator variable to maintain the full sample. All costs are in 2016 dollars. Salary (column 5) is denominated in thousands of dollars; workload (column 6) is class sections taught per FTE faculty member; class size (column 7) is student credit hours per class section; non-personnel (column 8) is expressed as a share of total instructional costs. Standard errors clustered on institution appear in parentheses and all models are weighted by total student credit hours*IPW. ***p<.001; **p<.01; *p<.05; ~p<0.1