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September 1, 2024

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In response to the call for submissions for the Chong Liew Summer Research Paper Awards, I am pleased to submit my job market paper titled "Dollars and Degrees: The Asymmetric Impact of State Appropriations on STEM and Non-STEM Fields."

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Dollars and Degrees: The Asymmetric Impact of State Appropriations on STEM and Non-STEM Fields*

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September 1, 2024

Abstract

This study examines the differential impact of state appropriations on STEM and non-STEM degree completion at U.S. public four-year institutions. Using a panel dataset from 2003 to 2019 and a Bartik-style instrumental variables approach, I find that state funding disproportionately affects STEM degree completion, with little to no impact on Non-STEM degrees. A 10% increase in state appropriations leads to a 3.4% increase in STEM degrees conferred, primarily four years after the funding change. This effect is concentrated among male students, science STEM majors, and non-selective institutions. Increased state support leads to higher institutional spending, and more STEM programs–factors that impact STEM degree completion more than non-STEM fields.

Keywords: State appropriations, STEM degrees, public four-year institutions, Bartik-style instrumental variable.

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1 Introduction

To meet the demand for STEM professionals and harness the social and economic spillovers of STEM education, the President's Council of Advisors on Science and Technology (PCAST) recommended a 34% increase in STEM graduates over current rates (PCAST, 2012). This is due to the significant economic benefits of STEM education, which are crucial for economic prosperity and social mobility (Wolniak et al., 2008, Carnevale et al., 2011, Bacovic et al., 2022). Approximately 44% of US college students enroll in public 4-year universities, with a higher proportion of these students coming from low-income backgrounds compared to those at private institutions (Pew Research Center, 2019, National Student Clearinghouse Research Center, 2024).

Public colleges and universities have experienced a decline in state appropriations, particularly following the Great Recession. Between 2001 and 2019, state appropriations for public higher education institutions in constant 2019 dollars decreased by 2.2%, declining from $82.6 billion to $80.8 billion (Cummings et al., 2021). The literature examines how state funding for higher education affects various aspects of student and institutional outcomes, including faculty composition, enrollment, completion rates, student debt, and credit scores (Deming and Walters, 2018, Chakrabarti et al., 2020, Hinrichs, 2022). This paper contributes by highlighting the asymmetric effects of state appropriations on STEM and non-STEM degree completion.[1]

Given the resource-intensive nature of STEM fields (Altonji and Zimmerman, 2019, Hemelt et al., 2021), I hypothesize that state appropriations have a significantly higher effect on STEM degree completion through two primary mechanisms. First, state funding enables colleges to adapt to labor market demands by introducing new programs, which are particularly pertinent for STEM majors. Second, the allocation of resources may have a more pronounced impact on STEM fields due to their greater reliance on production inputs.[2]

[1]On average, public universities received approximately $15.4 million less in state funding from 2015 to 2019 compared to 2003 to 2007 (see summary statistics in Table 1). From 2001 to 2019, full-time equivalent (FTE) student enrollment in public higher education institutions increased by 25.3%, growing from 8.7 million to 10.9 million students (Cummings et al., 2021).

[2]In their analysis of the Florida State University System, Altonji and Zimmerman (2019) reveal substantial program-level cost disparities, with per-credit expenditures ranging from $450 for engineering and health sciences to $200-$250 for social sciences, mathematics, business, and psychology. Reductions in state funding could also lead

To test these hypotheses, I construct a unique panel dataset from various sources and employ a Bartik-like instrumental variable (IV) approach commonly used in related literature (Deming and Walters, 2018, Chakrabarti et al., 2020, Hinrichs, 2022). The panel data includes the number of degrees conferred in specific majors at each public 4-year institution, as well as these institutions' expenditures and tuition from the Integrated Postsecondary Education Data System (IPEDS) from 2003 to 2019 (National Center for Education Statistics, 2022, 2019). The dataset also incorporates state-level higher education spending from the State Higher Education Executive Officers Association (2023), and economic and demographic variables from the University of Kentucky Center for Poverty Research (2023). Additionally, the panel includes institution-specific county-level economic and demographic variables from the Bureau of Economic Analysis and the U.S. Census Bureau.[3]

The analysis addresses endogeneity concerns stemming from reverse causality, selection of high-achieving students into well-funded institutions, and potential omitted variable bias through the implementation of a Bartik-like instrument. This instrument sidesteps the endogeneity issue by interacting the historical dependence of universities on state funding (shares) with the current state-level appropriations (shifts). My instrument differs from those in prior works in two key aspects: first, it extends 12 years before the first year of the data, and second, it constructs the share using five historical years (1987 to 1991) to provide a more accurate estimate of the historical shares.

The findings indicate that state appropriations have a significant effect on STEM degree completion and little effect on non-STEM field completion. The elasticities range between 0.24 and 0.34, depending on the cohort of students graduating in 4 (normal time), 5, or 6 years. The upper bound elasticity indicates that a 10% increase in state appropriations leads to a 3.4% increase in the number of students graduating with a bachelor's degree in each STEM major.

Next, I examine how the effect varies by institutional selectivity, STEM subfields, race, and gender. The observed effect is predominantly localized within non-selective institutions, attributable

to higher tuition fees, potentially altering the student preference for STEM majors compared to non-STEM majors.

[3]For classification of programs as STEM (Science, Technology, Engineering, and Mathematics), I use the STEM Designated Degree Program list from the U.S. Department of Homeland Security (DHS).

to their limited capacity to diversify revenue streams or access alternative funding sources (Bound et al., 2019). I also find that the effect is most relevant to science-related STEM fields, with a significant effect for minorities only in engineering majors. The gender analysis indicates that state appropriations have no significant effect on female STEM major completion.[4]

To investigate the driving mechanisms, I first examine the effect of state funding on two factors: spending (e.g., institutional grants and academic support), and the number of programs offered. I then analyze how these factors differentially influence STEM and non-STEM degree completion. The mechanisms analysis reveals that state appropriations have a significant effect on college spending and the number of fields offered. These factors, in turn, have a substantially greater effect on STEM field degree completion compared to non-STEM fields.[5]

The findings remain robust to various checks. Following Goldsmith-Pinkham et al. (2020), I demonstrate that the results are robust to the exclusion of institutions with the largest Rotemberg weights (a measure of relevance in generating the identifying variation in the instrument). The findings are also robust to the use of an alternative IV of aggregate state-level appropriations, following Webber (2017), Bound et al. (2019, 2020). A placebo analysis, which assigns false STEM designations to non-STEM majors, shows that the observed effects are not random.

The remainder of this paper is organized as follows: Sections 2 and 3 introduce the literature and conceptual framework. Section 4 describes the data and presents descriptive statistics. Section 5 outlines the empirical strategy. Section 6 presents the main results and explores potential mechanisms. Section 7 examines heterogeneous effects across various dimensions. Section 8 presents robustness checks, and Section 9 concludes.

[4]This result corroborates the literature suggesting that the gender gap in STEM fields is due to factors such as social expectations and stereotypes, peer group preferences, professional expectations regarding the personality of STEM graduates, and females being more risk-averse towards low grades (Crosnoe et al., 2008, Shapiro and Williams, 2012, Cheryan et al., 2015, Brenøe and Zölitz, 2020, Ahn et al., 2024).

[5]The mechanisms involve examining the effect of the number of majors offered, and university expenditures on STEM and non-STEM degree completion. The Bartik-like instrument is not feasible here because the size of public universities remains nearly constant over time. For instance, flagship universities consistently maintain the largest share of total state-level university expenditure. I assess the omitted variable bias of the OLS estimate by presenting breakdown points following Diegert et al. (2022) and Oster (2019)

2 Literature Review

This paper contributes to several strands of literature examining the impacts of state funding on higher education outcomes. Numerous studies have documented the decline in state support for public higher education, particularly following the Great Recession of 2008 (Bound et al., 2019, Chakrabarti et al., 2020). In response to these funding cuts, public universities have employed various strategies to maintain their operations and educational quality.

Bound et al. (2020) find that public research universities responded to a 10% reduction in state funding with a 16% increase in foreign undergraduate enrollment. This finding highlights how institutions leverage out-of-state tuition revenue to offset state funding losses. Similarly, Webber (2017) shows that state divestment in higher education is associated with increases in in-state tuition at public universities. On the expenditure side, Deming and Walters (2018) and Bound et al. (2019) document reductions in spending at public universities in response to state funding cuts.

The literature has also examined how changes in state funding affect student outcomes. Chakrabarti et al. (2020) show that students take on more debt at public universities experiencing state funding cuts, with negative implications for their long-term financial outcomes. Importantly, the impacts of funding changes are not uniform across all students and institutions. Bound et al. (2019) and Chakrabarti et al. (2020) find that the negative effects of funding cuts tend to be larger for lower-income students and at less selective institutions.

While the literature has extensively documented the general impacts of state funding changes, less attention has been paid to how these effects might differ across academic disciplines. This gap is particularly relevant given the growing policy interest in STEM education and the resource-intensive nature of STEM fields. Altonji and Zimmerman (2019) and Hemelt et al. (2021) provide evidence on the differential costs of producing graduates across majors. They find that STEM fields, particularly engineering and health sciences, have substantially higher per-credit and per-graduate costs compared to fields like business or social sciences. This cost differential suggests that STEM programs may be more sensitive to changes in institutional resources. Hinrichs (2022) examines the effects of state appropriations on employment at higher education institutions, finding significant impacts on part-time faculty employment, but does not specifically address differential effects across academic fields.

The importance of STEM education for economic growth and social mobility has been highlighted by several studies (Carnevale et al., 2011, Wolniak et al., 2008, Bacovic et al., 2022). However, the literature has not yet fully explored how state funding changes might differentially affect STEM vs. non-STEM degree production. The mechanisms through which state funding impacts degree production in different fields are not well understood. Finally, there is a need for more research on how the effects of state funding changes might vary across different types of institutions and student demographics within the context of STEM education.

This paper aims to address these gaps by examining the differential impact of state appropriations on STEM and non-STEM degree completion, exploring the mechanisms behind these effects, and investigating heterogeneity across institution types and student characteristics. By doing so, it contributes to the understanding of how public funding shapes the production of human capital in critical fields for economic growth and innovation. The study builds on the existing literature by leveraging a unique panel dataset and employing a Bartik-style instrumental variables approach, similar to methods used in recent studies (Webber, 2017, Deming and Walters, 2018, Bound et al., 2019, Chakrabarti et al., 2020, Hinrichs, 2022).

3 Conceptual Framework

To analyze how state appropriations affect degree completion in public universities, I develop a model of a college's optimization problem. The model, detailed in Appendix C, provides insights into the mechanisms through which funding impacts degree production, with a focus on differentiating between STEM and non-STEM fields.[6]

[6]In fiscal year 2019-20, the top two revenue sources for 4-year public institutions were tuition and fees (20.29%) and state appropriations (16.69%). In contrast, in fiscal year 2007-08, state appropriations (23.83%) exceeded tuition and fees (17.93%) as the primary revenue source (National Center for Education Statistics, 2024).

Consider a representative public university that aims to maximize degree production subject to a budget constraint. I hypothesize that the university's production function for degrees follows a Cobb-Douglas form, depending on instructional spending, financial aid, academic support, and the number of programs offered. The number of programs is assumed to be a function of instructional spending, capturing the idea that increased instructional resources enable universities to offer a wider array of programs.[7]

The model yields the following key prediction for the marginal effect of state appropriations on degree production:

$$\frac{\partial Y}{\partial R_s} = (\alpha + \beta + \gamma + \eta\theta)\frac{Y}{R_s + R_n} \tag{1}$$

where Y is the number of degrees produced, R_s is state appropriations, R_n is revenue from other sources, and α, β, γ, η, and θ are parameters representing output elasticities with respect to different inputs. This framework suggests two reasons why state appropriations may have a greater effect on STEM degree completion:

1. *Resource intensity*: STEM fields typically require more expensive core production inputs and more intensive tutoring and mentoring. For instance, instructional expenditures per student credit hour are 92% higher for electrical engineering compared to English-related courses, and per-credit expenditures range from \$450 for engineering and health sciences to \$200-\$250 for social sciences, mathematics, business, and psychology (Altonji and Zimmerman, 2019, Hemelt et al., 2021). Moreover, STEM courses typically demand more intensive tutoring and mentoring, as well as smaller class sizes (Bettinger and Baker, 2014, Kara et al., 2021).This suggests that the elasticity of output with respect to instructional spending (α) and academic support spending (γ) may be larger for STEM fields.

2. *Program diversity*: The rapid development of new technologies may necessitate more frequent updates to STEM curricula (Autor and Dorn, 2013). This implies that the elasticity of

[7] I employ the Cobb-Douglas function for its tractable properties and for consistency with my empirical approach and data (see Appendix B for a background discussion on the objective function of public institutions).

programs with respect to instructional spending (θ) and the elasticity of output with respect to program offerings (η) may be larger for STEM fields.

If these hypotheses hold, I would expect $(\alpha+\beta+\gamma+\eta\theta)_{STEM} > (\alpha+\beta+\gamma+\eta\theta)_{non-STEM}$, implying a larger marginal effect of state appropriations on STEM degree production. This framework motivates my empirical strategy to estimate and compare the elasticities of STEM and non-STEM degree completion with respect to state appropriations. It also guides my investigation of the mechanisms through which state funding affects degree production, including its impact on different categories of university spending and program offerings.

The model also suggests potential sources of heterogeneity in the effects of state funding. Universities with different initial levels of resources (R_n) or different production technologies (as captured by the elasticity parameters) may respond differently to changes in state appropriations. This motivates my empirical analysis of heterogeneous effects across institution types.

4 Data and Descriptive Statistics

4.1 Data Sources

The Integrated Postsecondary Education Data System (IPEDS), administered by the National Center for Education Statistics (NCES), serves as a comprehensive source of data on various facets of postsecondary education in the United States. The system encompasses a series of surveys that collect information on enrollment trends, graduation rates, and the characteristics of institutions that are eligible to disburse federal student aid funds, including Pell Grants and Stafford Loans. As mandated, these institutions must submit their data to the NCES via the IPEDS surveys (National Center for Education Statistics, 2022, 2019). A survey of particular significance within this collection is the Completions survey, which meticulously records the number of academic awards and degrees conferred—categorized by program using a 6-digit Classification of Instructional Programs (CIP) code—at each public four-year institution over a period extending from 2003 to 2019

I incorporate a comprehensive set of control variables derived from the University of Kentucky Center for Poverty Research (2023) to account for the multifaceted economic, political, and demographic characteristics at the state level. These variables encompass the state-mandated minimum wage, per capita personal income, and the poverty rate, alongside a binary indicator for the presence of a Democrat governor. Additionally, I include metrics indicative of social welfare engagement, quantified as the number of recipients per 100,000 population for programs such as the Supplemental Nutrition Assistance Program (SNAP), Medicaid, and Temporary Assistance for Needy Families (TANF). To further refine the demographic controls, I integrate data on the state population aged 18 to 24, sourced from the U.S. Census Bureau.

Complementing the state-level controls, I also introduce a series of county-level variables that may exert influence on enrollment decisions (Manski and Wise, 1983, Card, 1993, Betts and McFarland, 1995). These include the young adult population (aged 18 to 24), local per-capita personal income, and the unemployment rate. Moreover, I consider vital statistics such as births and deaths per 100,000 population, as well as the total population and its breakdown by gender and ethnicity, including male, white, black, and Hispanic demographics. The data for these county-level variables are procured from the Bureau of Economic Analysis and the U.S. Census Bureau.

Lastly, one important data source is the state budget expenditures to higher education or SHEEO Grapevine data from the State Higher Education Executive Officers Association (2023). This source provides the state and year level data on total expenditures allocated to higher education. The finance survey from IPEDS provides the college-level appropriations to each college over time, but SHEEO Grapevine total values are more complete and precise.

I use the STEM Designated Degree Program list from the U.S. Department of Homeland Security (DHS) to classify programs as STEM (Science, Technology, Engineering, and Mathematics) or non-STEM. This list includes the CIP (Classification of Instructional Programs) codes for majors that the department considers part of STEM fields (Immigration and Enforcement, 2022). I then utilize the National Center for Education Statistics CIP code crosswalks to harmonize all codes to the 2010 classification.[8]

4.2 Financial Trends

Table 1 presents summary statistics for college spending, state appropriations, number of STEM and non-STEM degrees, and number of programs offered by major type across two periods: the first and last five years of the dataset. On average, public 4-year institutions received approximately \$15.4 million less in state support from 2015 to 2019 compared to the period from 2003 to 2007, representing a decrease of 15.3%. The data indicates a significant increase in the cost of college attendance for the average university, with an approximate rise of \$2,113 (31.94%) in sticker price (published tuition and fees) and \$932 (7.56%) in net price (total cost minus all grants and aid). Concurrently, there has been an accompanying growth in institutional expenditures. This spending growth is expected due to increasing population and enrollments over time.

Figure 1 illustrates the temporal changes in real state appropriations per capita. Subfigure (a) demonstrates that the distribution, as time progresses, exhibits a more pronounced left tail, indicating an increased probability of lower funding allocations over time. Subfigure (b) reveals that pre-Great Recession state funding per student in 2008 was \$5,435. However, post-2008, state funding continued to decline, reaching its nadir of \$4,357 in 2012. Although state appropriations increased after 2012, they did not return to pre-Great Recession levels. These raw appropriation amounts do not explicitly demonstrate the covariation between state funding and college spending or prices over time.

Figure 2 compares the percentage annual changes in college spending and tuition with state appropriations over time. Prior to the 2008 Great Recession, average growth in college spending aligned closely with state funding, while tuition decreased. Post-2008, average per-student state appropriations declined sharply, reaching -10% in 2010. In response to this reduction in state fund-

[8]To align education with industry needs, the Department of Homeland Security (DHS) designates certain degree programs as fields of study in science, technology, engineering, and mathematics (STEM) for the 24-month Optional Practical Training extension available to foreign student graduates seeking employment in the United States (U.S. Department of Homeland Security, 2023). Appendix Table A25 shows the list of DHS STEM-designated programs.

ing, per-student total spending decreased to approximately -2.5% in the same year. Concurrently, tuition growth increased to slightly above 5% in 2009. After 2010, spending and state funding exhibited a positive correlation with fluctuating growth, although state appropriations growth post-2015 remained below pre-Great Recession levels. From 2012 onward, tuition growth remained relatively stable near zero, largely due to the implementation of tuition caps and freezes by 24 states (Deming and Walters, 2018, Miller and Park, 2022). In sum, college spending demonstrates a positive correlation with the level of state support received, suggesting that state funding may influence degree completion through the spending channel.

The relationship between state funding and college spending and pricing decisions is illustrated in Figure 3. By regressing spending and pricing variables on leads and lags of state appropriations, while controlling for potential confounding factors, one can observe the dependence of public colleges on state funding. The elasticities of total expenditures and academic support with respect to state appropriations are substantially larger in magnitude than those of sticker or net price. This finding suggests that state appropriations could influence student completion rates, particularly in majors that are most dependent on college resources (e.g., STEM fields).

4.3 Degree Completion

Table 1 also presents summary statistics for the number of degrees conferred by major type—STEM or non-STEM. There are significantly more non-STEM majors than STEM majors. Additionally, STEM majors have a smaller average number of degrees conferred. The literature shows that expected earnings, comparative advantage in a major, and subjective tastes are the main reasons for STEM major choice (Berger, 1988, Montmarquette et al., 2002, Arcidiacono, 2004, Arcidiacono et al., 2012, Wiswall and Zafar, 2015).[9]

The literature also identifies various drivers of STEM major choice, including preferences and

[9]Table A1 provides a comprehensive list of variables, including county and state covariates, for the full sample across all majors. Appendix Table A3 provides similar descriptive statistics disaggregated by gender and race. Appendix Table A4 presents a breakdown of the number of degrees by major type (STEM or non-STEM) and examines the differences within each major type for two periods: the first and last five years of the dataset.

non-pecuniary aspects, academic preparation, high school curriculum, labor market discrimination, and peer influence and support (Berger, 1988, Altonji et al., 2012, Ketenci et al., 2020, Card and Payne, 2021). This paper contributes to this body of research by examining how state funding influences the completion of STEM majors. Specifically, I investigate whether state appropriations have a greater effect on STEM majors compared to non-STEM majors.

Table 1 shows significant trends in higher education from 2003-2007 to 2015-2019. STEM degree production increases more sharply (67.1%) than non-STEM (11.5%), with STEM programs also expanding significantly by 13.6%. This suggests a growing emphasis on STEM education. Larger standard deviations in the later period, especially for degree counts, indicate increasing variability across institutions. This may reflect growing disparities due to a $15.3 million reduction in state appropriations, which non-selective universities might struggle to manage, potentially widening gaps in the higher education landscape.[10]

Figure 4 shows the relationship between the total number of different STEM degrees and the event of maximum reduction in state funding. To illustrate the relationship between state appropriations and STEM degree completion, I sum the number of STEM degrees conferred by all public 4-year institutions in the state before and after a maximum decrease in state funding for each institution and STEM major. Most institutions received the largest reduction in state funding between 2009 and 2012. With the exception of computer and information-related STEM majors, a reduction in state funding halts the growth of STEM degrees, with biological and biomedical fields experiencing the most significant drop. Figure A1 shows the results for non-STEM majors. Business and management-related non-STEM majors appear to be the most responsive to state budget cuts. This simple correlation, however, does not take into account the confounding factors that affect state funding and degree completions. The next section discusses the empirical strategy that addresses this endogeneity problem.

[10]Table A2 presents the summary statistics for the number of degrees by gender and race at university-program-year level.

5 Empirical strategy

I use a panel data on public 4-year universities and regress institution-level numbers of degrees conferred for specific majors (i.e., at the 6-digit CIP level) on state appropriations, and state and county economic and demographic conditions. Observations on university (i) located in state s and county c, program j, and the year t as follows:

$$y_{ijsct} = \beta_0 + \beta_1 \mathrm{Appr}_{ist} + X_{st}\phi + W_{ct}\rho + \gamma_i + \alpha_j + \delta_t + \epsilon_{ijsct} \qquad (2)$$

where y refers to the dependent variable of interest, Appr_{ist} is the institutional-level appropriations, X is state-level time-varying controls, W is county-level time-varying controls, and γ, α, and δ to institution-, program type-, and year-specific fixed effects. Hence, the model controls for time-invariant characteristics of institutions and program/major types (6-digit CIP) to account for labor demand for each field, as well as for macroeconomic and other temporal shocks affecting all institutions. I use the following log-log model so that coefficients can be directly interpreted as elasticities (Ω_{ijsct} refers to all controls and fixed effects):

$$\log(y_{ijsct}) = \beta_0 + \beta_1 \log(\mathrm{Appr}_{ist}) + \Omega_{ijsct} + \epsilon_{ijsct} \qquad (3)$$

However, this model suffers from serious endogeneity problems due to either omitted variable bias or reverse causality. Omitted variable bias may result in biased estimates if confounders correlate with both state funding and degree completion. For instance, colleges may adjust their curricula or other unobserved aspects that attract both more state funding and higher degree completion rates. Additionally, higher degree completion could be part of the formula through which states allocate funding, leading to reverse causality. To address this challenge, I use the following Bartik-like instrumental variable $\log(Z_{ist})$ (Bartik, 1991):

$$Z_{ist} = \left(\frac{\sum_{\tau=87}^{91} \mathrm{Appr}_{is\tau}}{\sum_{\tau=87}^{91} \mathrm{Rev}_{is\tau}} \right) \times \left(\frac{\mathrm{Appr}_{st}}{\mathrm{Pop}_{st}} \right) \tag{4}$$

Where $\mathrm{Appr_{is\tau}}$ and $\mathrm{Appr_{st}}$ refer respectively to the institution and state-level appropriation, $\mathrm{Rev_{is}}$ to the institution's total revenue, and $\mathrm{Pop_{st}}$ to the state college-aged population (i.e., population aged 18 to 24). The first term is the historical share, measuring how reliant each institution has been on state appropriations. The second term is the aggregate state-level appropriations per the state college-aged population. The share is useful for purging variation resulting from endogenous college factors driven by state funding. For example, the historical shares or reliance on state appropriations ensure the use of variation that is net of any state funding adjustment due to evolving college unobserved factors such as the ability to acquire income from other sources (e.g., increased donations or selectivity-driven out-of-state enrollment). The shift (per college-aged population state-level appropriations) is considered exogenous because it affects all state institutions uniformly, and because states determine their higher education budget in advance (Parmley et al., 2009, Deming and Walters, 2018, Hinrichs, 2022).[11]

While related literature, notably Deming and Walters (2018), Chakrabarti et al. (2020), Hinrichs (2022), has employed a similar instrumental variable, my approach differs in two aspects. First, it uses historical shares that go back at least 12 years from the first year of the panel data (the first year of data is 2003, and the last year in the shift is 1991). Going back in time over a decade strengthens the exogeneity assumption of the shares. Second, I use a more reliable measure of the share by taking the average over five years—from 1987 to 1991. This avoids any cyclicality in state funding allocation to specific institutions over time and hence reduces any potential measurement error.[12]

A new strand of econometric literature has emerged recently, calling into question different

[11]This instrument is widely used in the immigration literature (Bartik, 1991, Blanchard et al., 1992, Card, 2001, Autor et al., 2013). The findings are robust to the instrument scaling; using Z instead of $\log(Z)$ produces similar results.

[12]For example, an institution could receive more or less state appropriations in a particular year in a cyclical fashion, so using only a single historical cross-section may not capture the true reliance on state funding.

parts of the identification assumptions of Bartik instruments. Whereas Goldsmith-Pinkham et al. (2020) argues that the identification comes from the historical shares, Borusyak et al. (2022) contends that the exogeneity comes from the aggregate shifts. In my context, the identification is most likely derived from the shares for at least two reasons.

First, most state legislatures consider the higher education budget a so-called "balance wheel", implying the allocation of what remains after addressing other priorities such as Medicaid or K-12 education (Bell, 2008, Bound et al., 2019). This suggests that aggregate appropriations at the state level are likely uncorrelated with college-specific factors driving degree completion at the university level, especially given that most states have balanced budget requirements. In 1977, 33 states required balanced budgets, but by 2015, this number had grown to 46, with 37 states adopting constitutional balanced budget requirements (Rueben and Randall, 2017). By 2020, Vermont remained the only state without any balanced budget requirement (Tax Policy Center, 2020). Second, the dependence on state funding, especially for small colleges, may not change drastically over time. Hence, I implement Goldsmith-Pinkham et al. (2020) in my robustness checks.[13]

6 Results

6.1 The Effect of State Appropriations on Degree Completion, by STEM Type

Table 2 presents the baseline results of the impact of state appropriations on degree completions, comparing STEM fields to non-STEM fields. A comparison of Panels (a) and (b) reveals a pronounced effect on STEM degrees, particularly at $t + 4$, which aligns with the expected four-year graduation timeline. This temporal juncture marks a statistically significant influence solely for STEM degrees. The elasticity of 0.341 indicates that a 10% increase in state appropriations leads to a 3.41% increase in the number of STEM degrees conferred in each STEM major on average.

[13] Given the presence of competing approaches, Wright (2022) recommends that researchers carefully select the most appropriate identification assumption based on the specific context of their study.

Based on mean values, this implies that approximately \$10 million in additional state funding corresponds to an additional degree in each STEM major for students who complete their studies within the standard four-year period.

Advancing to $t + 5$, the period indicative of a five-year graduation span, the STEM coefficient remains statistically significant at the 5% level, while the non-STEM one becomes weakly significant at the 10% level. The addition of county control variables reduces the magnitude of the non-STEM coefficient while keeping the STEM one intact. Hence, the non-STEM estimate is, at best, an upper bound. The magnitude of the STEM coefficient is approximately 1.6 times larger. The final coefficient for the cohort of students who graduate in six years $t + 6$ remains significant only for STEM degrees.

The first-stage F-statistics provide strong evidence for the relevance of the instrumental variable in both the STEM and non-STEM models. For STEM degrees, the F-statistics range from 99.742 to 205.53 across different lead specifications, indicating a robust correlation between the instrument and the endogenous regressor. The non-STEM models exhibit even larger F-statistics, ranging from 260.50 to 678.11. This difference in magnitude is likely attributable, at least in part, to the substantially larger sample size for non-STEM programs, which affords greater precision in the first-stage estimates. These robust F-statistics suggest that the instrument is highly correlated with the endogenous regressor, mitigating concerns about weak instrument bias.[14]

Building on my previous specification with year, institution, and program fixed effects, I explore the robustness of my findings by introducing more granular fixed effects in Table A6. I estimate models with program-by-year and institution-by-program fixed effects to control for time-varying factors common across programs and institutions, as well as for characteristics unique to each program within an institution. For example, this approach accounts for changes in national accreditation standards for engineering programs and the reputation of a specific university's biology department. The results remain quantitatively and qualitatively consistent across these more

[14]Table A5 presents the OLS estimates. Adding controls increases STEM coefficients and decreases non-STEM coefficients, suggesting potential downward bias for STEM and upward bias for non-STEM in simpler models. This indicates that parsimonious specifications may underestimate STEM effects and overestimate non-STEM effects on the outcome variable.

demanding specifications. The instrumented state appropriations continue to show a statistically significant effect only on STEM degrees, with no significant impact on non-STEM programs.

Table A7 shows similar 2SLS results for master's degrees, indicating that state appropriations have a positive effect exclusively on STEM-related master's degrees. The doctoral degrees, as shown in Table A8, indicate a null effect of state appropriations on either major type. This will be discussed further in the heterogeneous effect section, which shows that the state appropriation effect is concentrated within non-selective universities, implying that selective institutions offering higher degrees like doctorates are not affected.

While the extant literature (e.g., Deming and Walters (2018), Bound et al. (2019)) has established that state appropriations influence college aggregate enrollment and completion, this study delves into the nuances of college completion by examining the differential impacts on STEM and non-STEM degrees. The findings reveal that STEM degrees exhibit a higher sensitivity to state funding.

The subsequent section explores the underlying mechanisms driving the disproportionate effect of state appropriations on STEM degrees. Specifically, I examine two potential mechanisms: college spending (with a focus on specific areas such as academic support) and the number of programs offered (the choice set of majors within each field).

6.2 The Effect of State Appropriations on Spending and Number of Programs offered

State support influences public universities' financial decisions, affecting the amount universities invest in their core operations, such as instruction, academic support, and institutional grants. Figure 5 (see Table A9 for further estimation details) indicates that state support leads to higher aggregate and specific expenditures. Interestingly, the elasticities for academic support related expenditures (e.g., tutoring, advising, and mentoring) surpass those for instructional expenditures (e.g., faculty salaries and wages). Hence, state support increases spending on tutoring and other supportive academic activities. As STEM courses tend to be more time-intensive to study for, increased tutor spending at the institutional level may benefit STEM majors more than non-STEM majors. The last panel (d) shows that institutions also invest more in grants (fellowships and aid). Consequently, state support is directly linked to the investment levels in core operations at public institutions, with elasticities ranging from 0.036 to 0.31.[15]

State appropriations can also impact the ability of colleges to offer new programs to meet market demand. To study this effect, I investigate how state funding affects the number of distinct STEM and non-STEM degree programs offered by each college over the data period. Figure 6 (see Table A10 for more estimation details) reports the results. State appropriations impact the number of distinct programs for both STEM and non-STEM majors. However, the elasticity of state appropriations for STEM degrees is approximately 1.6 times that of non-STEM degrees at $t + 0$. This larger effect on STEM programs is consistent with the rapid market developments in STEM fields, such as advancements in artificial intelligence, data science, and programming languages.[16]

The results in all tables are robust to the inclusion of more granular demographic and economic covariates at the universities' location counties. The first-stage F-statistic exceeds 20 for the concurrent effect (t+0), indicating relatively strong instrument relevance.

Although state funding has varying impacts on different factors (spending and program offerings), it remains unclear whether these factors significantly influence bachelor's degree completion. Hence, it is important to establish whether these factors have differing influences on STEM and non-STEM bachelor's degree completion.

[15]Spending measures are only available at the institution level from IPEDS surveys, not disaggregated by department or program. The analysis thus uses college-year level data instead of college-program-year level data

[16]Appendix Table A12 shows higher state appropriations lead to lower college prices. A 10% funding increase reduces sticker prices by 1.04% and net prices by 1.8%. Effects persist but decrease over time. While state funding may influence degree numbers through pricing, small elasticities suggest limited impact.

6.3 The Effect of Prices, Spending and Number of Programs offered on Completion

This mechanism section involves determining the effect of college financial variables (expenditures), number of distinct STEM or non-STEM majors offered, and prices (tuition and net price) on degree completion. The use of the previously employed Bartik instrumental variable is not feasible in this case because spending historical shares remain nearly constant over time. For example, flagship universities in each state consistently maintain the highest share of aggregated expenditures, as their relative size remains intact.

For this purpose, I employ OLS as in Equation (3), with *Appr* replaced by the expenditure, distinct number of programs, and price variables. I supplement these OLS results with an assessment of omitted variable bias using the approaches of Diegert et al. (2022) and Oster (2019). Specifically, I present breakdown points, which are the thresholds at which the estimated results could be overturned due to omitted variable bias. A higher breakdown point indicates that the results are less likely to be significantly influenced by unobserved factors.[17]

Figure 7 (see Table A11 for further estimation details) indicates that most of these factors are significant, and their impact is more pronounced for STEM degrees. Panel (a) shows that the number of distinct programs offered is associated with more bachelor's degrees only for STEM majors. Combined with the previous findings, state appropriations have a greater impact on STEM degree completion by increasing the number of distinct STEM majors, which in turn attracts new students. The insignificance of the coefficient for non-STEM implies that increases in non-STEM majors due to state appropriations lead only to student shuffling within these majors.[18]

The table (panel a) also reports the breakdown point ($\hat{\bar{r}}_X^{bp}(\%)$) following Diegert et al. (2022). This breakdown statistic refers to the threshold of the allowed maximum share of selection on unobservables out of selection on observables such that the coefficient would no longer statistically

[17] While these methods do not necessarily provide causal estimation, they are highly effective in quantifying the risk of omitted variable bias. The Diegert et al. (2022) approach is more robust as it relaxes the assumption that omitted variables must be uncorrelated with the included controls.

[18] The number of distinct programs is collinear with the program fixed effects. Therefore, STEM and non-STEM degrees are summed at the institution and year level. Other variables vary only at the institution level.

be different from zero. The breakdown point of 80% indicates that selection on unobservables due to omitted variables must be at least 80% as large as selection on observables to reject the OLS estimates and conclude that the coefficient is zero. A breakdown point close to zero would imply that the OLS results are unlikely to be causal. Since the breakpoints are high, the findings are robust and omitted variable bias is less of a concern.

Figure 7 indicates that total spending is positively associated with the number of both STEM and non-STEM degrees, but the elasticity for STEM degrees is approximately 64% higher than that for non-STEM degrees (4-year graduates). The figure shows that academic support spending has more than triple the effect on STEM degrees for graduation within 4 years (4-year graduates). Additionally, academic support spending has a statistically significant effect only on STEM degrees for graduation within 5 and 6 years. Similarly, the findings indicate that instructional spending has a greater effect on STEM degrees at 4-year graduates—the elasticity for STEM is more than double that of non-STEM degrees. For institutional grants (fellowships and aid), the effect is significant only for STEM majors, but the elasticities are smaller than those of spending. The breakpoints from Table A11 support the robustness of the estimates in panels b, c, and e, but the breakpoint in panel d is relatively smaller, implying sensitivity to selection on unobservable factors.

Panels (f) and (g) in Table A11 show that prices have minimal or no effect on non-STEM major completion. Sticker price has a negative effect on STEM degrees with elasticities of -0.13 and -0.11 for cohorts graduating in 4 and 5 years, respectively. This implies that some STEM-oriented students on the margin may have shifted their major choice or college choice, opting for the private sector. The outside option could also be no enrollment in college or other preferences such as seeking vocational education. Nonetheless, net price has no statistically significant effect on the number of degrees, which implies that the actual cost of college attendance net of aid and grants does not influence the number of degrees conferred. One potential explanation for this is that grant aid from various sources has been increasing since 2006, reaching approximately $8,000 on average at public 4-year universities in 2019, while the net cost of attendance has remained stagnant since 2015 at $20,000 (Ma, 2021).

Whereas findings in Figures 5 and 6 show that state appropriations have a significant positive effect on college attendance cost, spending, and number of offered majors, Figure 7 shows that most of these factors are highly important for STEM completion. Consequently, state appropriations have a disproportionately greater effect on STEM major completion due to the dependence of STEM fields on resources and the ability of institutions to respond to new emerging demand by offering new majors. Figure A2 shows that the sensitivity analysis breakdown points remain at the same level or improve for different assumptions of correlation (0 to 1) between observed and unobserved variables.[19]

7 Heterogeneous effects

7.1 Selectively

Selectivity in higher education refers to the degree of competitiveness and exclusivity in a university's admissions process. Highly selective institutions typically admit a small percentage of applicants, often those with exceptional academic credentials, standardized test scores, and extracurricular achievements. These institutions generally have stronger reputations and greater financial resources through alumni donations, research grants, and endowments. In contrast, less selective or non-selective institutions have more inclusive admissions policies, admitting a larger proportion of applicants with varying academic backgrounds.[20]

Selective universities tend to have a greater number of distinct revenue sources. Bound et al. (2019) show that such institutions are able to compensate for lost state appropriations by increasing private gifts and endowments. This suggests that my main findings in Table 2 are primarily driven by non-selective institutions that have limited sources of income to smooth any income shock.

[19] As shown in Table A11, Sticker price appears to have negative effects only on STEM completion within 4 or 5 years, but net price has no effect on either major's completion. The omitted variable sensitivity test is also robust to alternative estimation methods following Oster (2019), as shown in Table A13.

[20] There is no consensus in the literature for the definition of selectivity. For example, Deming and Walters (2018) uses Barron's Profile of American Colleges, while Bound et al. (2019) uses membership in the American Association of Universities (AAU).

Figure 8 (see Table A14 for further estimation details) confirms this hypothesis, showing that the effect is significant only for non-selective institutions. The effect remains significant only for STEM degrees, as in the main results.

These findings are based on the Carnegie classification of selectivity. Table A19 shows similar results with an alternative definition of selectivity, instead using membership in the Association of American Universities or Barron's Profile of American Colleges. The coefficients for STEM degrees remain significant at the 5% level and are larger in magnitude.[21]

Land-grant institutions have a broad mission that includes a strong emphasis on STEM fields, especially in areas like agriculture, engineering, and applied sciences, which align with their historical mandate (the Acts of 1862 and 1890). Appendix Table A21 shows that the state appropriations elasticity of STEM degrees for land-grant institutions ranges between 1.19 and 1.76, suggesting increasing returns to scale at these institutions.

7.2 Majors

This paper makes a significant contribution by identifying specific disciplines within STEM and non-STEM majors that respond to changes in state funding. The 2SLS regression results presented in Table 3 indicate that the impact of state appropriations on the number of bachelor's degrees conferred in STEM fields is not uniform across all disciplines.[22]

The analysis reveals a negligible effect on engineering majors, while a more pronounced influence is observed in the fields of biological and biomedical sciences, mathematics and statistics, as well as physical sciences. It is noteworthy that the 'other' category encompasses a few select majors from predominantly non-STEM disciplines that are recognized as STEM by the Department of Homeland Security (DHS). The insignificance of the coefficient for the engineering fields can

[21] Similarly, Appendix Table A20 indicates that the effect is concentrated among non-doctoral institutions, most of which are also non-selective.

[22] The table presents the top five most frequent majors at the 2-digit CIP code level. DHS considers the following majors at the 2-digit CIP code level as STEM: Engineering (CIP code 14), Biological and Biomedical Sciences (CIP code 26), Mathematics and Statistics (CIP code 27), and Physical Sciences (CIP code 40). See Table A25 for further details about DHS STEM designated programs.

be attributed to many factors, including peer effects and student cohort preparedness or quality. Hemelt et al. (2021) show that engineering programs are more expensive than English programs mainly due to higher wages and lower teaching loads, which may then factor into better student outcomes within these fields.

However, the next subsection reveals significance for engineering among some underrepresented gender and racial groups. Overall, the effect is concentrated within non-computer or information sciences and mathematics-related STEM fields.[23]

Table A15 shows the heterogeneous effects for non-STEM majors; the marginal effect of state appropriations on non-STEM majors is concentrated within English majors and other fields (Table A22 shows that English majors constitute most of the "other" category in panel f). Changes in teaching loads and class size within these fields, as demonstrated by Hemelt et al. (2021), may explain these results.

7.3 Gender and Race

There is a growing body of literature that attempts to explain the gender gap in STEM majors (Altonji et al., 2016, Kahn and Ginther, 2017). I contribute to this literature by examining the effect of state funding on STEM degrees by gender. Table 4 shows that the state appropriation effect for female students is null. This finding supports the growing set of literature that attributes the gap to non-resource-inputs related factors such as social expectations and stereotypes, peer group preferences, professional expectations, and non-STEM-oriented males being less likely to enter university (Crosnoe et al., 2008, Shapiro and Williams, 2012, Speer, 2017, Cheryan et al., 2015, Brenøe and Zölitz, 2020, Card and Payne, 2021). A study by Ahn et al. (2024) showed that curving grades towards a B for all courses can help diminish the gender gap in STEM fields, as female students tend to be more risk-averse towards low grades.

The primary findings, as presented in Table 4, indicate that the influence of state appropria-

[23]For example, only four programs in the social sciences are counted as STEM: "Econometrics and Quantitative Economics," "Cartography," "Archeology," and "Geographic Information Science and Cartography."

tions on STEM bachelor's degrees predominantly affects male students. Further analysis, detailed in Tables A16, A17, and A18, reveals that the effect varies by race, gender, and STEM degree types. The findings indicate a significant effect of state appropriations on Black male graduates in engineering-related fields. This implies that production inputs are critical for some underrepresented groups within the engineering discipline. Additionally, the analysis for females shows that state funding has a significant effect only on biological and biomedical science degree completion.

Future research opportunities lie in examining the underlying factors that drive the effects on specific racial groups, notably the null effects of state funding on Hispanic students across all majors, in contrast to other racial groups. One potential explanation for the lack of significance for Hispanic students could be the effectiveness of numerous programs designed to promote underrepresented minorities in STEM fields, particularly in states with large Hispanic populations such as New Mexico, Texas, Florida, and California (Crisp et al., 2009, Hernandez et al., 2013, Estrada et al., 2016). Further investigation into these programs and their interaction with state funding could provide valuable insights into the mechanisms underlying the observed disparities in STEM degree completion across racial groups.[24]

8 Robustness checks

To validate the reliability and consistency of the main findings, I conduct a series of robustness checks. This section presents three distinct approaches to assess the stability of the results. First, following Goldsmith-Pinkham et al. (2020), I examine the sensitivity of the instrumental variable (IV) estimates to the exclusion of influential universities. Second, I employ an alternative IV strategy using state-level appropriations, as in Webber (2017), Bound et al. (2019, 2020). Finally, I perform a placebo test using Monte Carlo simulations to further corroborate the robustness of the main results. These checks collectively provide a comprehensive evaluation of the validity and stability of the empirical findings, addressing potential concerns related to instrument construction,

[24]Some of the prominent programs include the New Mexico Alliance for Minority Participation, the Society of Hispanic Professional Engineers (SHPE), and Hispanic-Serving Institution (HSI) STEM programs.

endogeneity, and the possibility of spurious correlations.

8.1 IV Robustness

Following Goldsmith-Pinkham et al. (2020), I compute the relevance of each university in generating the identifying variation in each instrument (see equation 4). I find that public 4-year institutions from Colorado have the largest power in explaining variation of the instrument. Universities such as Colorado State University, University of Colorado, and other colleges from Colorado have the highest weights in the construction of the instrument (see Table A23 in the Appendix).

Table 6 demonstrates that the main estimates are robust to excluding the five universities with the highest Rotemberg weights. This exclusion increases the magnitude of the coefficients, with statistical significance remaining relevant for STEM fields only. Table A24 shows similar results when dropping the top 10 universities driving the identifying variation in the instrument. These findings indicate that the main results are robust and represent a lower bound estimate.

8.2 Alternative IV

Since states often use higher education appropriations as the balancing wheel for state budgets a few years in advance, some literature uses the aggregate state appropriations as an instrumental variable for the specific university-level appropriations. Similar to the instrument implemented by Webber (2017), Bound et al. (2019, 2020), I use the state-level appropriations as an instrument and report the findings in Table 5. The coefficients are smaller than the main results, but they remain significant only for the STEM degrees, indicating that my overall story holds.

8.3 Placebo test

To test the robustness of the main findings in Table 2, I conduct a falsification test involving Monte Carlo analysis. In this analysis, I first limit the data to non-STEM majors and randomly assign false STEM majors such that the share of STEM to non-STEM is preserved as in the original data, where approximately 30% of the majors are STEM. This random sample is drawn 10,000 times to perform the 2SLS estimation for each, as in the main results. Figure 9 shows the kernel density of the generated placebo coefficients on each variable lead. The dashed lines indicate the estimated placebo parameters, while the solid lines denote the actual estimated parameters in Table 2. The estimated true coefficients are further away from the center (randomly generated parameters). This indicates that the main findings are not random but robust.

9 Conclusion

This study provides compelling evidence that state appropriations have a significant and disproportionate effect on STEM degree completion in public four-year institutions. The findings reveal that a 10% increase in state funding leads to a 3.4% increase in STEM degrees conferred, primarily manifesting four years after the funding change. This effect is particularly pronounced in biological and biomedical sciences, mathematics, and physical sciences, while being largely concentrated among male students and non-selective institutions.

The analysis of potential mechanisms suggests that increased state support influences STEM degree completion through multiple channels. Higher institutional spending (especially on academic support), and an expanded array of STEM programs all contribute to improved outcomes in STEM fields. These findings underscore the resource-intensive nature of STEM education and the critical role of state funding in supporting these programs (Altonji and Zimmerman, 2019, Hemelt et al., 2021).

The heterogeneous effects observed across institution types, gender, and race highlight important considerations for policymakers. The concentration of effects in non-selective institutions suggests that these schools may be more vulnerable to changes in state funding and may require particular attention in funding decisions. These results have several important implications for higher education policy. They suggest that cuts to state appropriations may have outsized negative effects on STEM education, potentially hampering efforts to increase the STEM workforce (Griffith, 2010, Sjoquist and Winters, 2015, Bottia et al., 2018). The findings indicate that increased state funding could be an effective tool for boosting STEM degree completion, particularly at non-selective institutions.

While state support for operating costs has diminished over time, public universities have continued to increase their real assets per student almost linearly (see Figure A3). This trend suggests a shift in state funding toward long-term projects (e.g., STEM buildings or laboratory equipment), warranting investigation into the effect of college assets on student outcomes. In conclusion, this study underscores the critical role of state appropriations in supporting STEM education at public four-year institutions, providing important evidence to inform policymakers' deliberations on budget decisions and strategies to strengthen the STEM workforce.

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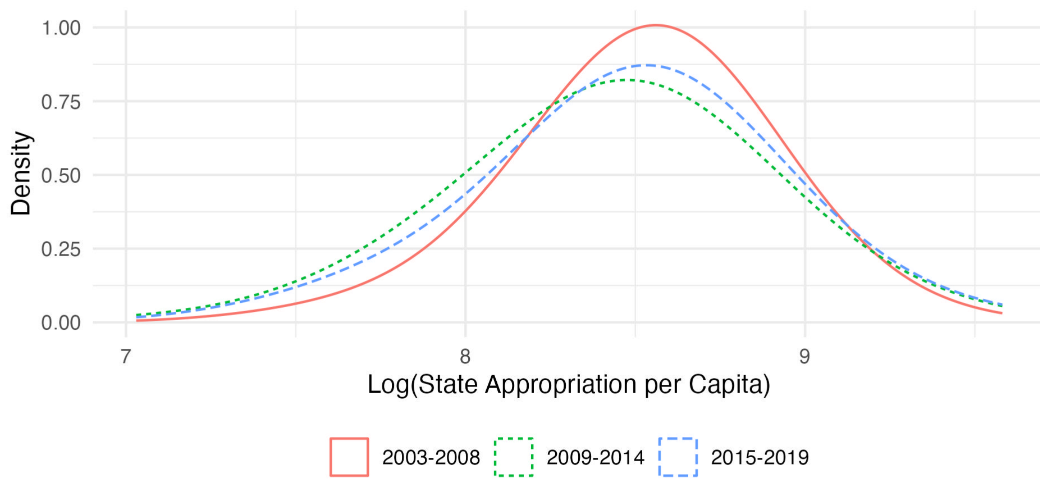
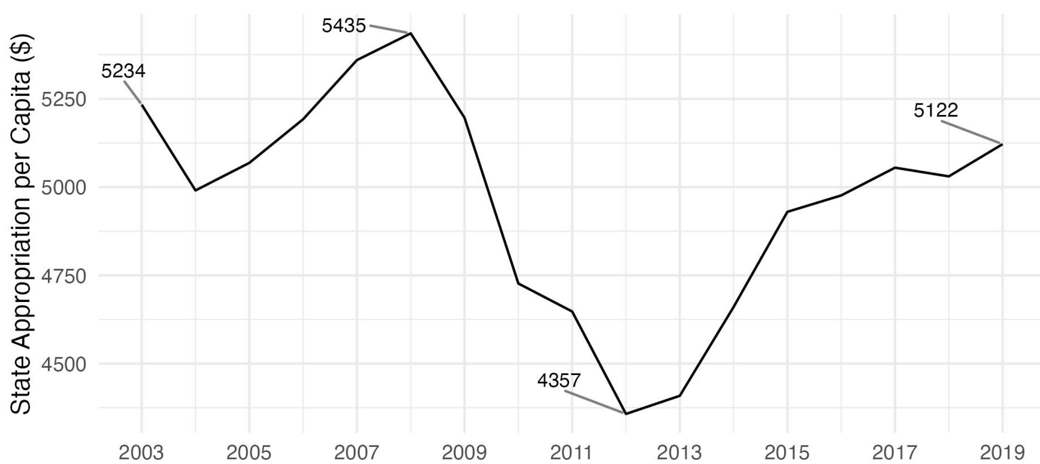
Figure 1: Trends in State Appropriations

(a) Distribution by Periods



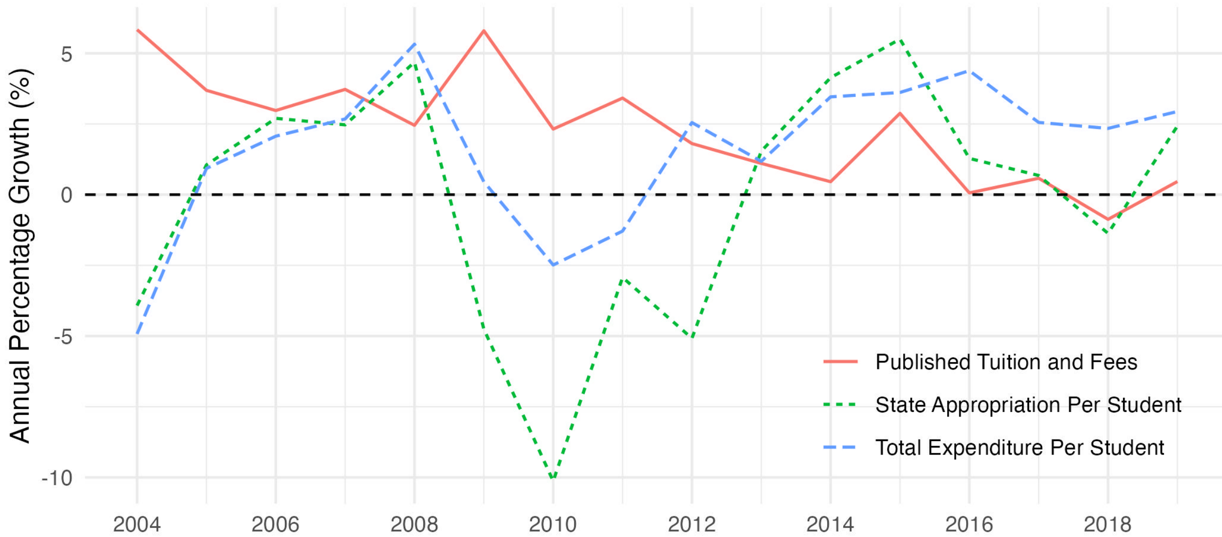
(b) Average over Time



SOURCES.— State Appropriation is extracted from the Grapevine report as documented in State Higher Education Executive Officers Association (2023). The population data for individuals aged 18 to 21 years within the state is acquired from U.S. Census Bureau (2024).
All monetary values are adjusted to 2019 dollar terms utilizing the Consumer Price Index (CPI) data provided by the Bureau of Labor Statistics (BLS).

NOTES.— Density plot (a) presents the distribution of log-transformed state appropriations per college-age population. The data spans equally spaced intervals from 2003 to 2019. A kernel density estimate (KDE) is utilized to offer a smooth approximation of the probability density function (PDF), providing insight into the underlying distribution. Figure (b) chronicles the evolution of average state expenditure on higher education per capita, focusing on the college-age demographic (ages 18 to 21), and tracks its progression over the specified time frame. The average is weighted by the state college-age population.

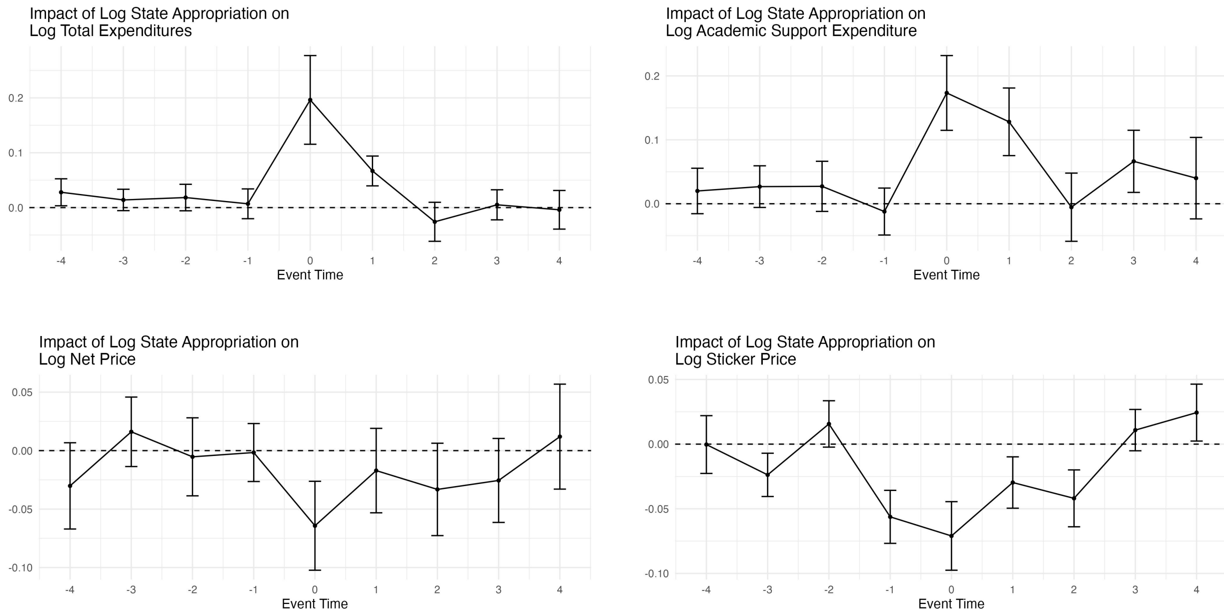
Figure 2: University Price, Appropriation and Expenditure Annual Changes



SOURCES.— Data on Published Tuition and Fees, as well as State Appropriation and Expenditure, are sourced from the Integrated Postsecondary Education Data System (IPEDS) as reported in U.S. Department of Education, National Center for Education Statistics (2024). Specifically, Published Tuition and Fees are derived from the Institutional Characteristics Survey (Student charges for academic year programs), while State Appropriation and Expenditure information is obtained from the Finance Survey. The per-student basis for state appropriations and expenditures is calculated using data from the 12-Month Enrollment Survey of IPEDS.
All monetary values are adjusted to 2019 dollar terms utilizing the Consumer Price Index (CPI) data provided by the Bureau of Labor Statistics (BLS)

NOTES.— The Figure illustrates the annual percentage change in the average sticker tuition and fees, state appropriations, and total expenditures per student at all public 4-year institutions.

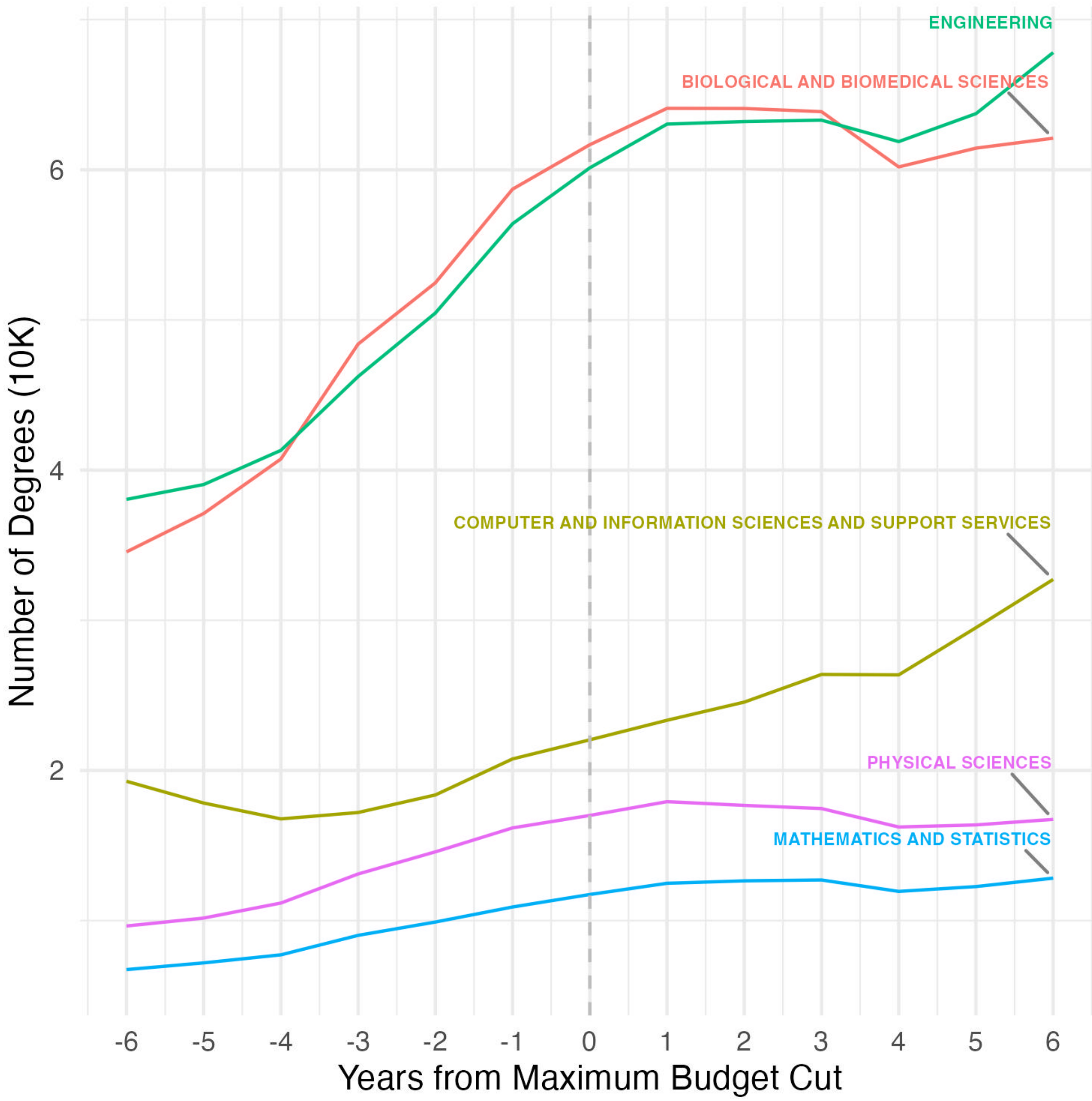
Figure 3: State Appropriations Vs. Prices and Spending



SOURCES.— All the data are sourced from the Integrated Postsecondary Education Data System (IPEDS) as reported in U.S. Department of Education, National Center for Education Statistics (2024). Specifically, Sticker Price which refers to published tuition and fees is derived from the Institutional Characteristics Survey (Student charges for academic year programs), Net Price from the Student Financial Aid and Net Price, and other variables from the Finance Survey.

NOTES.— The figure presents estimates and 95 percent confidence intervals from regressions of different expenditures or prices on lags and leads of state appropriations for all public 4-year institutions. Models include state level controls (i.e., log population, minimum wage, log personal income, log number of SNAP recipients, democratic governor dummy), county level controls (i.e., log population, share of population by race, log personal income, unemployment rate, birth and death rate) and institution and year fixed effects. Standard errors are clustered at the institution level.

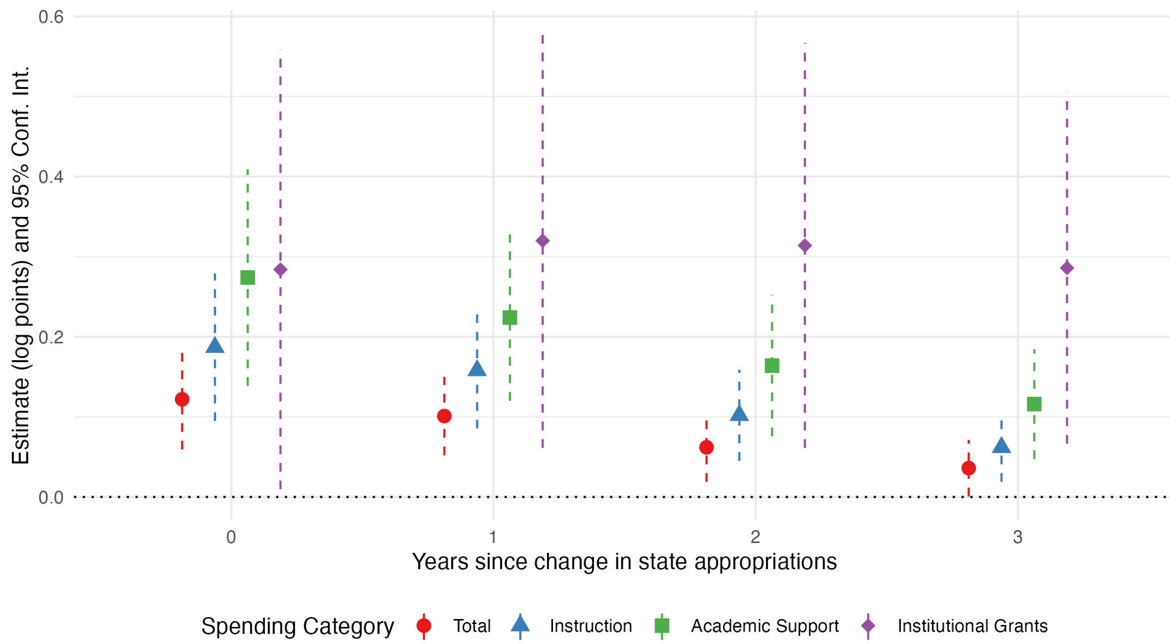
Figure 4: Number of STEM Bachelor Degrees vs. Budget Shock



SOURCES.— Data on Number of Degrees (Bachelor) and State Appropriation are sourced from the Integrated Postsecondary Education Data System (IPEDS) as reported in U.S. Department of Education, National Center for Education Statistics (2024). In particular, Number of Degrees is derived from the Completions–Awards/degrees conferred by program (6-digit CIP code), award level, race/ethnicity, and gender, while State Appropriation information is obtained from the Finance Survey. STEM classification is obtained from The U.S. Department of Homeland Security (2020).
All monetary values are adjusted to 2019 dollar terms utilizing the Consumer Price Index (CPI) data provided by the Bureau of Labor Statistics (BLS)

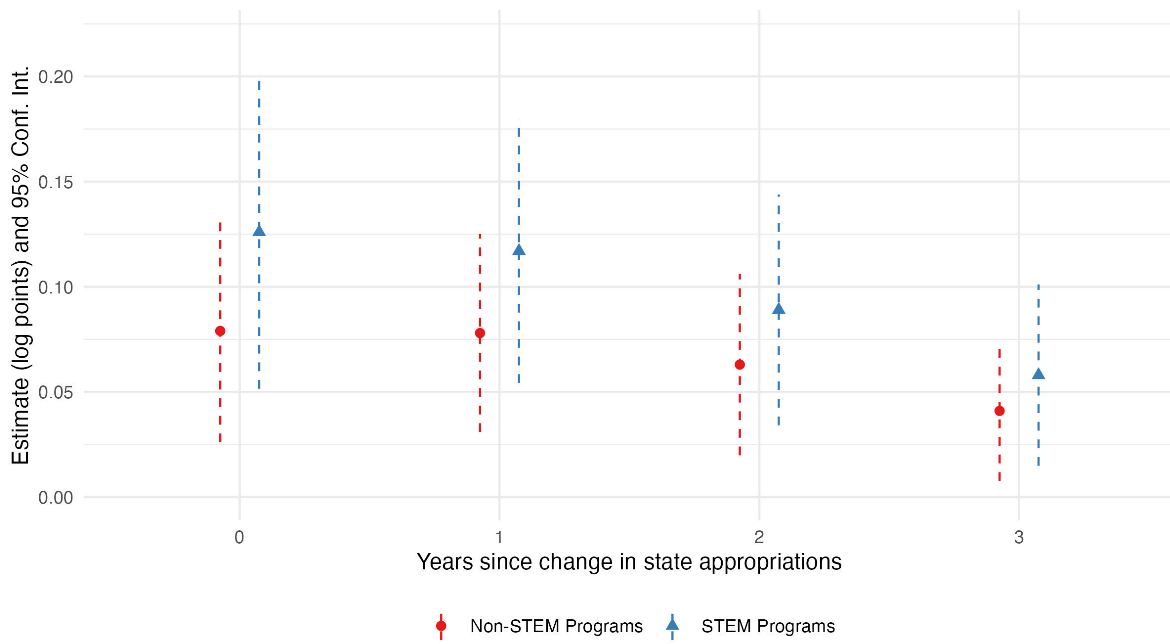
NOTES.— The unit of analysis is college-program type and year. The Figures displays yearly number of STEM bachelor's degrees awarded by all 4-year public institutions for four years before and after a maximum cut in state appropriations for each university in the period 2003 to 2019.

Figure 5: Effect of State Appropriations on Spending



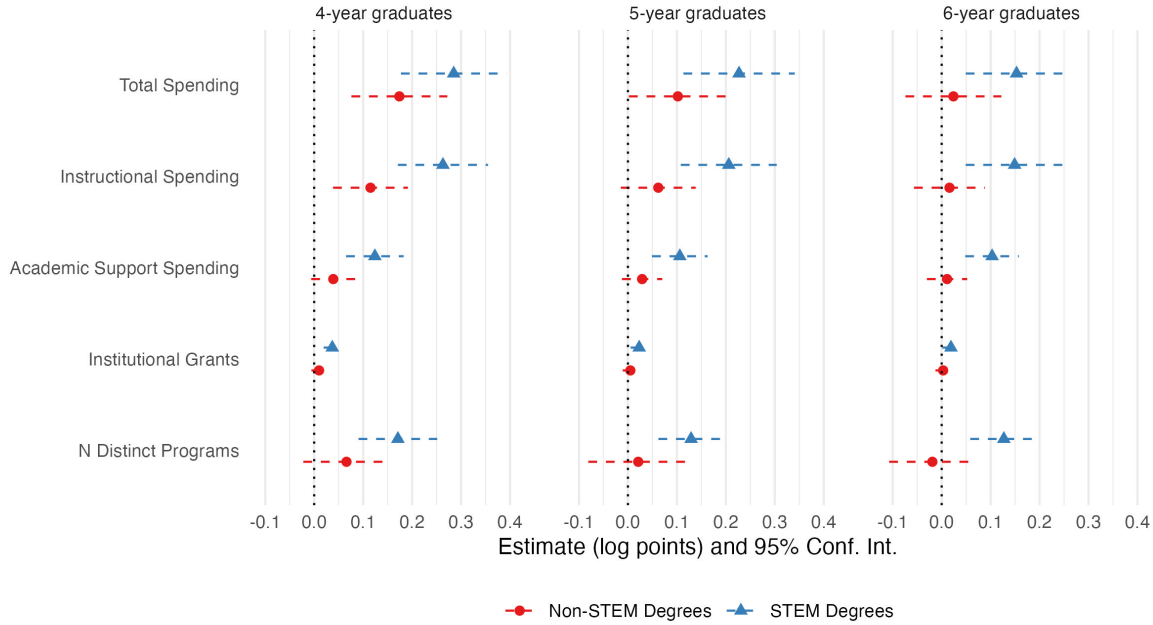
NOTES: Each estimate refers to a separate 2SLS regression. Academic support spending includes expenditures on tutoring, advising, mentoring, and other activities and services that support the institution's primary missions. The models include year and institution fixed effects, as well as time-varying county and state covariates, as described in Table 2. A lead of "t+i" (years since change in state appropriations, from 0 to 3) indicates the i^{th} lead of the outcome variable. The unit of analysis is at the institution-year level. Standard errors are clustered at the institution level. Further estimation details are provided in Table A9.

Figure 6: Effect of State Appropriations on Number of Programs



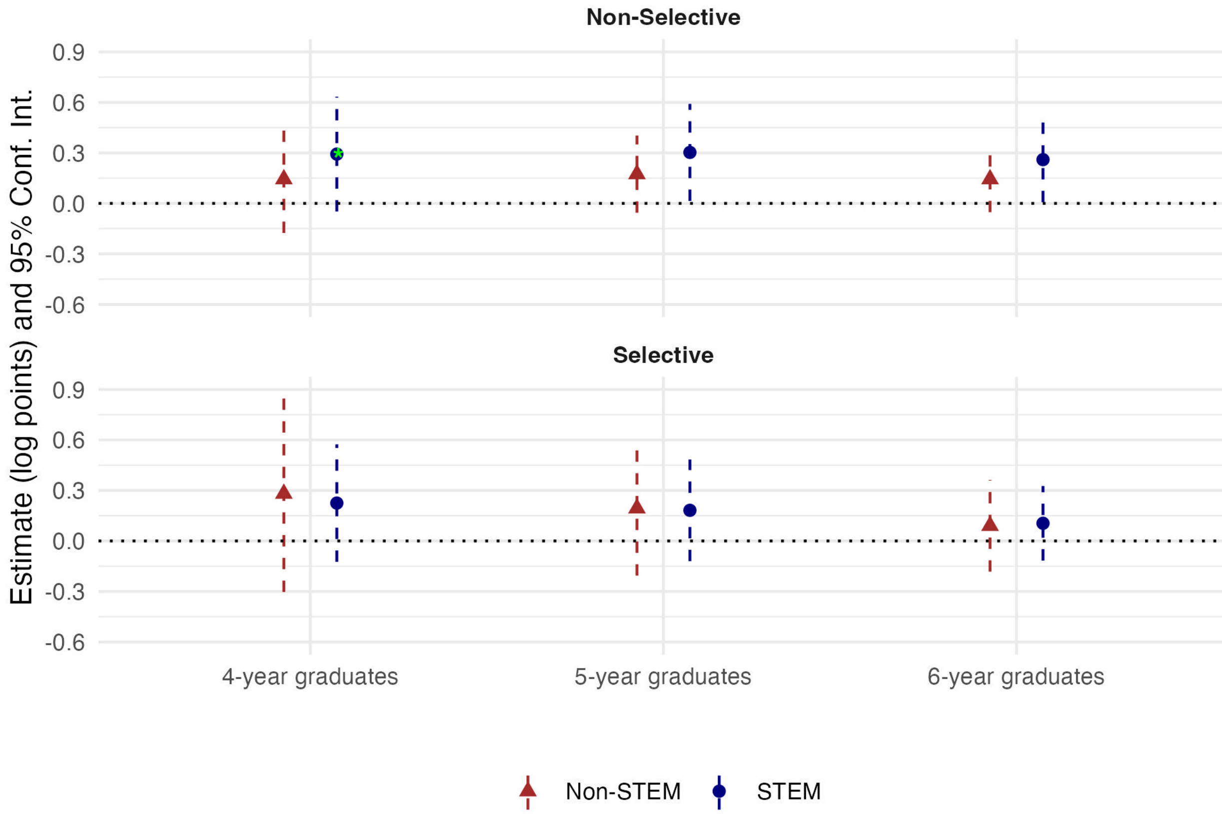
NOTES: Each estimate refers to a separate 2SLS regression. "N Distinct STEM/Non-STEM Programs" refers to the institution-level number of distinct programs offered within Science, Technology, Engineering, and Mathematics (STEM) or non-STEM fields. The models include year and institution fixed effects, as well as time-varying county and state covariates, as described in Table 2. A lead of "t+i" (years since change in state appropriations, from 0 to 3) indicates the i^{th} lead of the outcome variable. The unit of analysis is at the institution-year level. Standard errors are clustered at the institution level. Further estimation details are provided in Table A10.

Figure 7: Effect of Spending and Programs on Number of STEM and Non-STEM Degrees



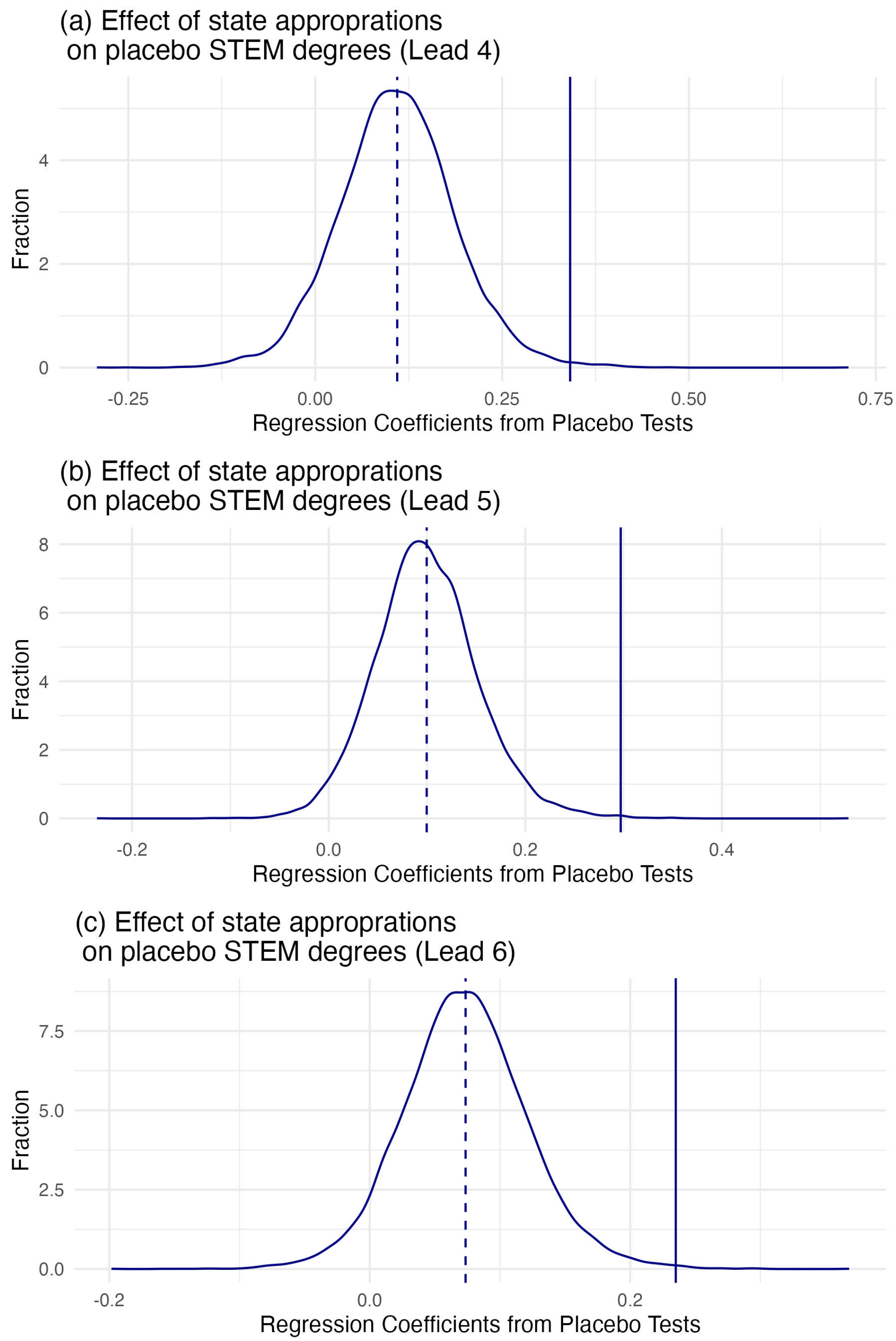
NOTES: Each estimate refers to a separate OLS regression. The STEM degree outcome variable (triangle estimates) is the logged number of undergraduate Science, Technology, Engineering, and Mathematics (STEM) bachelor's degrees conferred. For the non-STEM degrees (point estimates), the dependent variable is the logged number of non-STEM bachelor's degrees. "N Distinct Programs" refers to the institution-level number of distinct programs offered within STEM for the first three columns and within non-STEM for the last three columns. "Academic Support Expenditures" includes spending on tutoring, advising, mentoring, and other activities and services that support the institution's primary missions. The models include year and institution fixed effects, as well as time-varying county and state covariates, as described in Table 2. A lead of "t+i" (ranging from 3 to 6) indicates the i^{th} lead of the outcome variable. For example, the lead t+6 refers to the student cohort that completes bachelor's education in 6 years. The unit of analysis is at the institution-year level. Standard errors are clustered at the institution level. Further estimation details are provided in Table A11.

Figure 8: The Effect of State Appropriations on Bachelor's Degrees, by Institution Selectivity and Degree Type



NOTES: Each estimate refers to a separate 2SLS regression. The outcome variable is the logged number of undergraduate degrees (bachelor's) conferred for Science, Technology, Engineering, and Mathematics (STEM) majors or non-STEM majors. The star label refers to significance at 10% level. Selectivity is defined based on the Carnegie classification and refers to the institutions that are in the top 20th percentile of selectivity among all baccalaureate institutions with fewer than 20 percent of entering undergraduate transfers. Table A19 shows similar results based on the selectivity definition of AAU membership or being listed as competitive in Barron's Profiles of American Colleges. Further estimation details are provided in Table A14.

Figure 9: Placebo Test for the Effect of State Appropriations on STEM Degrees



NOTES.—The figure shows the kernel density plot of the coefficient on each outcome variable lead obtained from 10,000 different sets of placebo 2SLS regressions as in Table 2. The placebo test involves a Monte Carlo analysis in which STEM majors are randomly assigned across a bootstrap sample (random sample with replacement) drawn from the dataset that contains non-STEM majors only. The number of placebo STEM majors drawn is consistent with the share of STEM majors in the original data, which is 30.2% of all the majors. The dashed line gives the average point estimate of the coefficient on each placebo distribution, and the solid vertical line gives the estimated slope coefficient of each outcome variable as shown in Table 2.

STEM refers to Science, Technology, Engineering, and Mathematics programs or majors as designated by the Department of Homeland Security (DHS). Table A25 presents the complete list of STEM programs.

Table 1: Summary Statistics–College Spending and Prices

	2003 to 2007 (N=2765)		2015 to 2019 (N=3120)		
	Mean	SD	Mean	SD	Diff. in Means
State Appropriation ($M)	99.891	122.386	84.512	109.865	-15.380***
Total Expenditures ($M)	378.030	616.594	472.734	903.632	94.705***
Instructional Expenditures ($M)	102.937	138.909	138.006	210.066	35.070***
Academic Support Expenditures ($M)	25.907	40.942	39.786	74.053	13.879***
Institutional Grants ($M)	10.345	19.761	23.543	41.643	13.199***
N Non-STEM Degrees	1340.153	1323.535	1494.153	1597.454	154.000***
N STEM Degrees	319.187	441.898	533.467	789.146	214.279***
N of Non-STEM Programs	35.042	21.883	36.105	25.804	1.062
N of STEM Programs	12.551	9.194	14.258	11.108	1.706***

SOURCES.—All data are sourced from the Integrated Postsecondary Education Data System (IPEDS) as reported in U.S. Department of Education, National Center for Education Statistics (2024).

NOTES.—The unit of analysis is institution-year. All amounts are adjusted for inflation using the Consumer Price Index (CPI) and are presented in 2019 dollars. Table A1 shows summary statistics for all variables, including the state and county covariates.

Table 2: The Effect of State Appropriations on Bachelor's Degrees, by STEM Type

	Dependent Variable: Log Number of Bachelor Degrees							
	t+3		t+4		t+5		t+6	
Panel (a): STEM								
Log State Appropriations	0.181	0.172	0.326**	0.341**	0.297**	0.297**	0.251**	0.235**
	(0.172)	(0.176)	(0.160)	(0.169)	(0.130)	(0.130)	(0.111)	(0.108)
N Institutions	617	617	617	617	617	617	617	617
N Programs	339	339	339	339	339	339	339	339
Observations	94,249	92,804	85,574	84,262	77,206	76,019	69,228	68,157
F-test (1st stage)	110.51	99.742	129.83	114.24	205.53	182.92	193.32	171.02
Panel (b): Non-STEM								
Log State Appropriations	0.183	0.171	0.223	0.206	0.216*	0.188*	0.182*	0.142
	(0.198)	(0.219)	(0.158)	(0.170)	(0.113)	(0.111)	(0.098)	(0.091)
N Institutions	663	663	663	663	663	663	663	663
N Programs	783	783	783	783	783	783	783	783
Observations	263,276	259,969	238,383	235,340	214,454	211,681	191,533	189,026
F-test (1st stage)	298.97	260.50	405.29	363.31	678.11	632.93	608.29	583.50
Institution FE	✓	✓	✓	✓	✓	✓	✓	✓
Program FE (6-Digit CIP)	✓	✓	✓	✓	✓	✓	✓	✓
Year FE	✓	✓	✓	✓	✓	✓	✓	✓
State Controls	✓	✓	✓	✓	✓	✓	✓	✓
County Controls	×	✓	×	✓	×	✓	×	✓

NOTES.—Each panel and cell refers to a separate 2SLS regression. The outcome variable in panel (a) is the logged number of undergraduate Science, Technology, Engineering, and Mathematics (STEM) degrees (bachelor's) conferred. In panel (b), the dependent variable is the logged number of non-STEM bachelor's degrees. A lead of "t+i" (ranging from 3 to 6) indicates the ith lead of the outcome variable. For example, the lead t+6 refers to the student cohort that completes bachelor's education in 6 years. CIP refers to the Classification of Instructional Programs, which is used to categorize degree programs by specific majors (see Table A25 for the subset of STEM majors). The unit of analysis is at the institution, program (6-digit CIP), and year level. The models include year, program, and institution fixed effects, as well as time-varying county and state covariates. The state-level controls include poverty rate, logged population aged 18 to 24, per-capita personal income, minimum wage, number of Supplemental Nutrition Assistance Program (SNAP) recipients per 100,000 population, and number of Temporary Assistance for Needy Families (TANF) recipients per 100,000 population. The county-level controls include logged per-capita personal income, total population, unemployment rate, percentage of population by race (Hispanic, Black, and White), percentage of male population, and birth and death rates per 100,000 population. Standard errors are clustered at the institution level. *p < 0.10, **p < 0.05, ***p < 0.01

Table 3: The Effect of State Appropriations on STEM Bachelor's Degrees, by Program Type

	Dependent Variable: Log Number of STEM Bachelor Degrees							
	t+3		t+4		t+5		t+6	
Panel (a): Engineering								
Log State Appropriations	0.063	0.080	0.112	0.129	0.171	0.199	0.087	0.062
	(0.155)	(0.182)	(0.144)	(0.178)	(0.134)	(0.168)	(0.097)	(0.117)
N Institutions	326	326	326	326	326	326	326	326
N Programs	55	55	55	55	55	55	55	55
Observations	18,851	18,441	17,217	16,842	15,623	15,282	14,094	13,786
F-test (1st stage)	30.73	23.92	25.85	17.67	33.45	20.95	39.60	23.58
Panel (b): Physical Sciences								
Log State Appropriations	0.263	0.253	0.264*	0.303*	0.130	0.165	0.090	0.108
	(0.190)	(0.193)	(0.155)	(0.170)	(0.097)	(0.105)	(0.089)	(0.093)
N Institutions	485	485	485	485	485	485	485	485
N Programs	35	35	35	35	35	35	35	35
Observations	18,170	17,817	16,723	16,402	15,297	15,003	13,887	13,619
F-test (1st stage)	23.65	22.20	33.86	30.70	61.82	57.47	56.78	53.28
Panel (c): Biological and Biomedical Sciences								
Log State Appropriations	-0.018	0.005	0.452	0.507	0.521**	0.550**	0.426**	0.425**
	(0.382)	(0.392)	(0.337)	(0.353)	(0.258)	(0.264)	(0.211)	(0.207)
N Institutions	526	526	526	526	526	526	526	526
N Programs	66	66	66	66	66	66	66	66
Observations	15,406	15,250	13,988	13,846	12,623	12,494	11,320	11,203
F-test (1st stage)	14.22	12.78	18.35	16.34	30.24	28.40	25.41	24.82
Panel (d): Computer and Information Sciences and Support Services								
Log State Appropriations	-0.403	-0.554	-0.220	-0.287	0.071	0.060	0.303	0.331
	(0.372)	(0.417)	(0.286)	(0.311)	(0.203)	(0.204)	(0.250)	(0.256)
N Institutions	534	534	534	534	534	534	534	534
N Programs	26	26	26	26	26	26	26	26
Observations	9,754	9,590	8,774	8,625	7,841	7,707	6,960	6,839
F-test (1st stage)	10.63	9.227	13.95	12.77	22.16	21.67	18.78	18.11
Panel (e): Mathematics and Statistics								
Log State Appropriations	0.435*	0.407*	0.244	0.231	0.102	0.080	0.095	0.061
	(0.227)	(0.228)	(0.167)	(0.168)	(0.114)	(0.117)	(0.110)	(0.115)
N Institutions	503	503	503	503	503	503	503	503
N Programs	13	13	13	13	13	13	13	13
Observations	8,531	8,387	7,836	7,704	7,148	7,027	6,479	6,368
F-test (1st stage)	14.90	14.24	18.43	17.09	30.48	27.99	29.06	26.46
Panel (f): Others								
Log State Appropriations	0.534	0.499	0.867*	0.845	0.754*	0.660	0.691	0.568
	(0.531)	(0.536)	(0.497)	(0.520)	(0.444)	(0.419)	(0.446)	(0.410)
N Institutions	550	550	550	550	550	550	550	550
N Programs	144	144	144	144	144	144	144	144
Observations	23,537	23,319	21,036	20,843	18,674	18,506	16,488	16,342
F-test (1st stage)	19.28	18.95	22.94	22.61	33.00	33.02	26.99	27.55
Institution FE	✓	✓	✓	✓	✓	✓	✓	✓
Program FE (6-Digit CIP)	✓	✓	✓	✓	✓	✓	✓	✓
Year FE	✓	✓	✓	✓	✓	✓	✓	✓
State Controls	✓	✓	✓	✓	✓	✓	✓	✓
County Controls	×	✓	×	✓	×	✓	×	✓

NOTES.—Each panel and cell refers to a separate 2SLS regression and includes a subset of all sub-majors within the given global major 2-digit CIP code. The outcome variable is the logged number of undergraduate degrees (bachelor's) conferred for Science, Technology, Engineering, and Mathematics (STEM) majors. A lead of "t+i" (ranging from 4 to 6) indicates the ith lead of the outcome variable. The models include year, program, and institution fixed effects, as well as time-varying county and state covariates, as described in Table 2. Standard errors are clustered at the institution level. *p < 0.10, **p < 0.05, ***p < 0.01

Table 4: The Effect of State Appropriations on STEM Bachelor's Degrees, by Gender

	Dependent Variable: Log Number of STEM Bachelor Degrees							
	t+3		t+4		t+5		t+6	
Panel (b): Male								
Log State Appropriations	0.098	0.098	0.287*	0.305*	0.281**	0.296**	0.198*	0.195*
	(0.168)	(0.176)	(0.152)	(0.161)	(0.128)	(0.131)	(0.102)	(0.101)
Panel (c): Female								
Log State Appropriations	0.005	-0.003	0.130	0.157	0.085	0.083	0.091	0.078
	(0.183)	(0.187)	(0.152)	(0.164)	(0.109)	(0.114)	(0.101)	(0.104)
N Institutions	617	617	617	617	617	617	617	617
N Programs	339	339	339	339	339	339	339	339
Observations	94,249	92,804	85,574	84,262	77,206	76,019	69,228	68,157
F-test (1st stage)	110.51	99.74	129.83	114.24	205.53	182.92	193.32	171.02
Institution FE	✓	✓	✓	✓	✓	✓	✓	✓
Program FE (6-Digit CIP)	✓	✓	✓	✓	✓	✓	✓	✓
Year FE	✓	✓	✓	✓	✓	✓	✓	✓
State Controls	✓	✓	✓	✓	✓	✓	✓	✓
County Controls	×	✓	×	✓	×	✓	×	✓

NOTES.—Each panel and cell refers to a separate 2SLS regression. The outcome variable in panels (a) refers to the logged number of undergraduate Science, Technology, Engineering, and Mathematics (STEM) degrees (bachelors) conferred to male students, and in panel b to female students. A lead of "t+i" (ranging from 4 to 6) indicates the ith lead of the outcome variable. The models include year, program, and institution fixed effects, as well as time-varying county and state covariates, as described in Table 2. Standard errors are clustered at the institution level. *p < 0.10, **p < 0.05, ***p < 0.01

Table 5: The Effect of State Appropriations on STEM Bachelor's Degrees (Alternative IV)

	Dependent Variable: Log Number of STEM Bachelor Degrees							
	t+3		t+4		t+5		t+6	
Panel (a): STEM								
State appropriations	0.088	0.081	0.168*	0.176*	0.150**	0.150**	0.126**	0.118*
	(0.103)	(0.107)	(0.094)	(0.101)	(0.073)	(0.074)	(0.062)	(0.061)
N Institutions	617	617	617	617	617	617	617	617
N Programs	339	339	339	339	339	339	339	339
Observations	94,249	92,804	85,574	84,262	77,206	76,019	69,228	68,157
F-test (1st stage)	80.041	69.530	99.237	84.214	168.12	145.82	160.65	138.64
Panel (b): Non-STEM								
State appropriations	0.100	0.094	0.118	0.109	0.113*	0.098	0.095*	0.073
	(0.123)	(0.140)	(0.094)	(0.102)	(0.065)	(0.063)	(0.055)	(0.051)
N Institutions	663	663	663	663	663	663	663	663
N Programs	783	783	783	783	783	783	783	783
Observations	263,276	259,969	238,383	235,340	214,454	211,681	191,533	189,026
F-test (1st stage)	202.20	166.57	302.13	261.18	550.99	504.18	500.29	472.32
Institution FE	✓	✓	✓	✓	✓	✓	✓	✓
Program FE (6-Digit CIP)	✓	✓	✓	✓	✓	✓	✓	✓
Year FE	✓	✓	✓	✓	✓	✓	✓	✓
State Controls	✓	✓	✓	✓	✓	✓	✓	✓
County Controls	×	✓	×	✓	×	✓	×	✓

NOTES.—Each panel and cell refers to a separate 2SLS regression. The table replicates the main results in Table 2 using an alternative instrumental variable–the aggregate state-level appropriations following Bound et al. (2019). The outcome variable in panels (a) refers to the logged number of undergraduate Science, Technology, Engineering, and Mathematics (STEM) degrees (bachelors) conferred, and in panel b Non-stem. A lead of "t+i" (ranging from 4 to 6) indicates the ith lead of the outcome variable. The models include year, program, and institution fixed effects, as well as time-varying county and state covariates, as described in Table 2. Standard errors are clustered at the institution level. *p < 0.10, **p < 0.05, ***p < 0.01

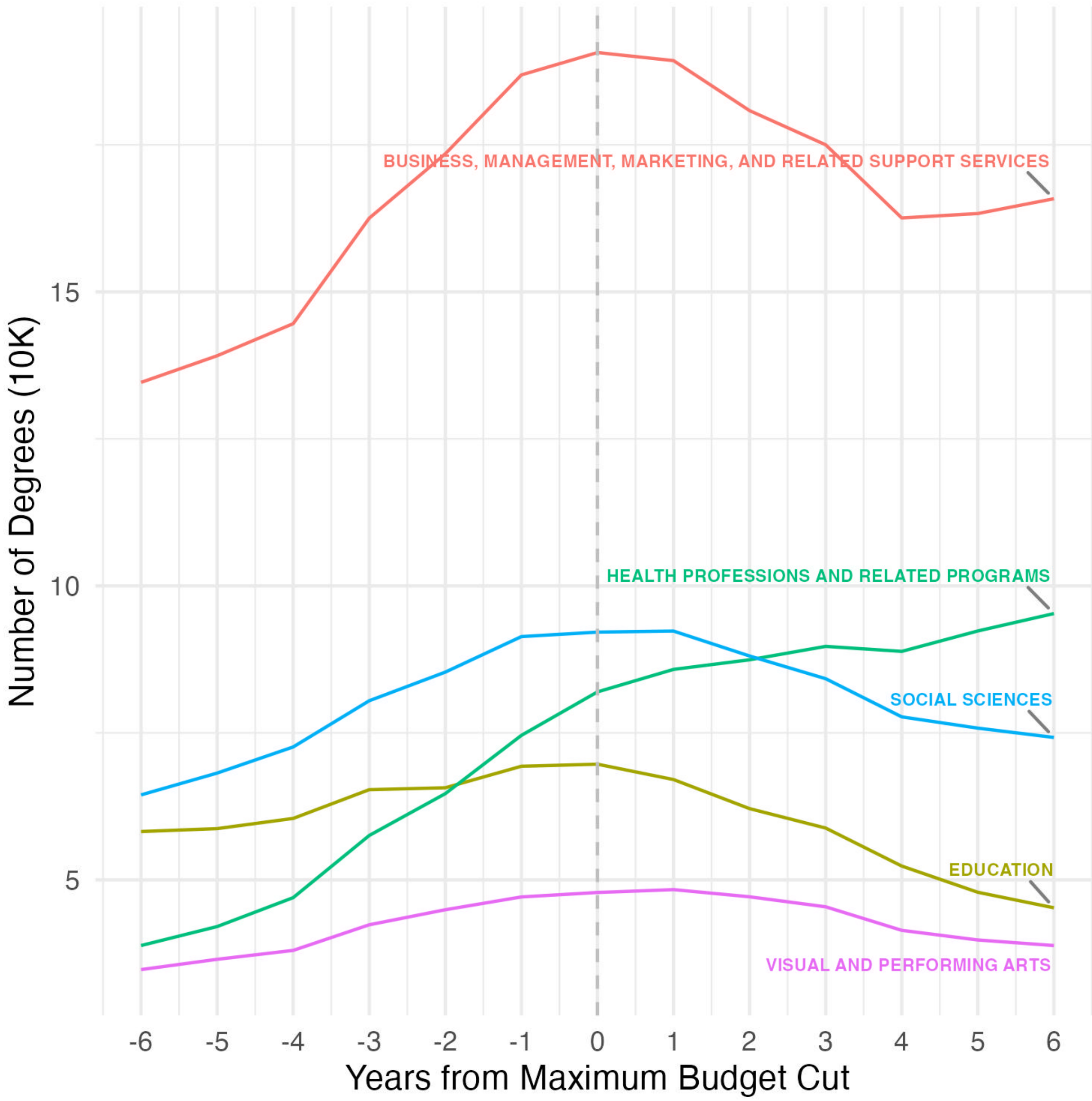
Table 6: Impact of State Appropriations on Bachelor's Degrees (Excluding Top 5 Rotemberg Weight Institutions)

	Dependent Variable: Log Number of Bachelor Degrees					
	t+4		t+5		t+6	
Panel (a): STEM						
Log State Appropriations	0.458*	0.483*	0.508**	0.510**	0.395**	0.378*
	(0.245)	(0.268)	(0.233)	(0.253)	(0.192)	(0.205)
N Institutions	617	617	617	617	617	617
N Programs	339	339	339	339	339	339
Observations	84,606	83,294	76,335	75,148	68,444	67,373
F-test (1st stage)	69.426	59.948	74.257	64.125	78.022	63.600
Panel (a): Non-STEM						
Log State Appropriations	0.272	0.248	0.310	0.262	0.267	0.202
	(0.259)	(0.280)	(0.211)	(0.213)	(0.184)	(0.180)
N Institutions	663	663	663	663	663	663
N Programs	783	783	783	783	783	783
Observations	236,321	233,278	212,596	209,823	189,866	187,359
F-test (1st stage)	220.67	194.32	258.75	241.38	241.29	224.88
Institution FE	✓	✓	✓	✓	✓	✓
Program FE (6-Digit CIP)	✓	✓	✓	✓	✓	✓
Year FE	✓	✓	✓	✓	✓	✓
State Controls	✓	✓	✓	✓	✓	✓
County Controls	×	✓	×	✓	×	✓

NOTES.—Each panel and cell refers to a separate 2SLS regression. The outcome variable in panel (a) is the logged number of undergraduate Science, Technology, Engineering, and Mathematics (STEM) degrees (bachelor's) conferred. In panel (b), the dependent variable is the logged number of non-STEM bachelor's degrees. A lead of "t+i" (ranging from 3 to 6) indicates the ith lead of the outcome variable. For example, the lead t+6 refers to the student cohort that completes bachelor's education in 6 years. CIP refers to the Classification of Instructional Programs, which is used to categorize degree programs by specific majors (see Table A25 for the subset of STEM majors). The Table replicates the main findings in Table 2 after omitting the top 5 institutions that have the highest Rotemberg weights shown in Table A23. Table A24 shows similar results after dropping top 10 weights instead. Standard errors are clustered at the institution level. *p < 0.10, **p < 0.05, ***p < 0.01

A Appendix

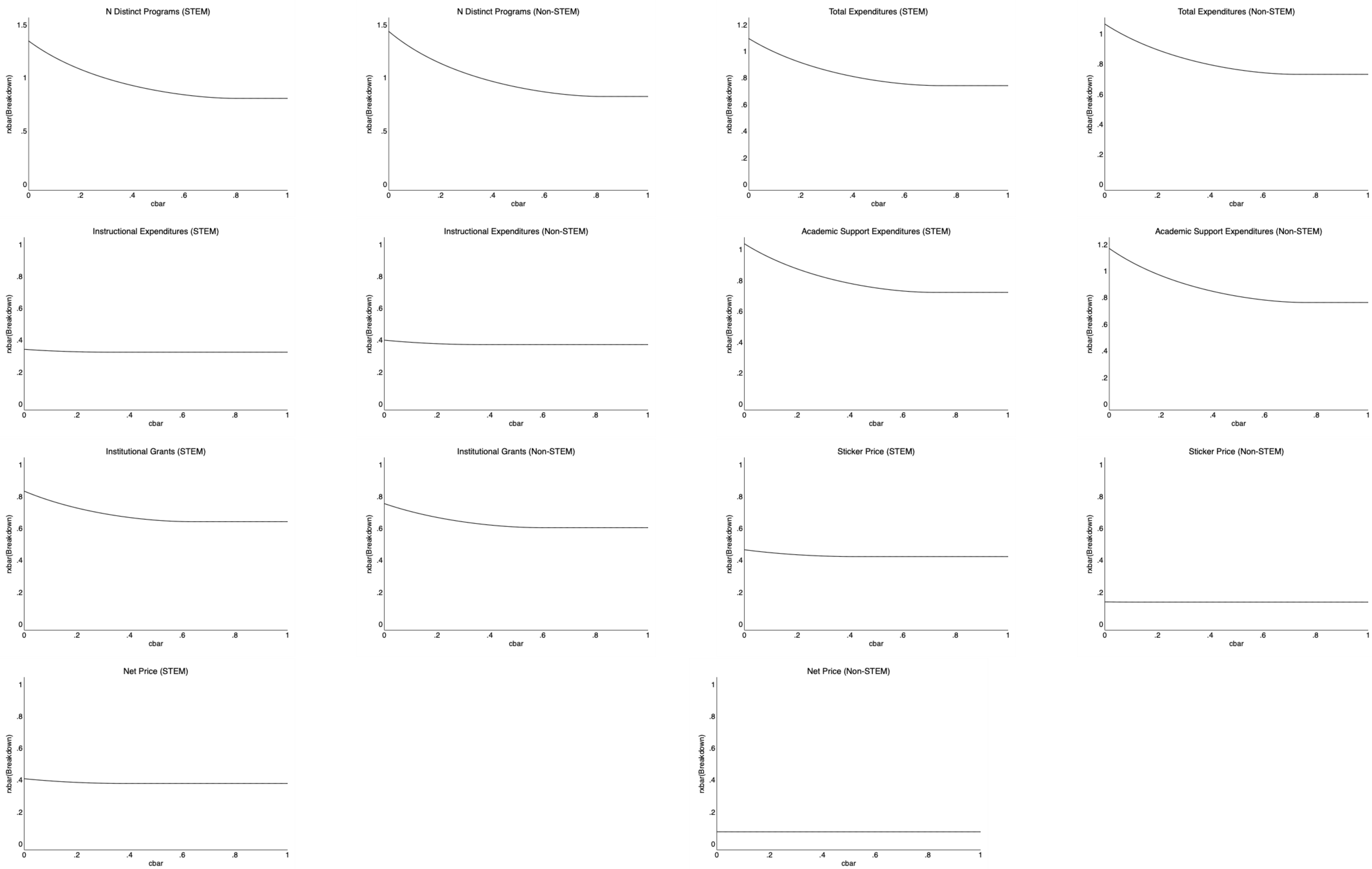
Figure A1: Number of Non-STEM Bachelor Degrees Vs. Budget Shock



SOURCES.— Data on Number of Degrees (Bachelor) and State Appropriation are sourced from the Integrated Postsecondary Education Data System (IPEDS) as reported in U.S. Department of Education, National Center for Education Statistics (2024). In particular, Number of Degrees is derived from the Completions–Awards/degrees conferred by program (6-digit CIP code), award level, race/ethnicity, and gender, while State Appropriation information is obtained from the Finance Survey. STEM classification is obtained from The U.S. Department of Homeland Security (2020).
All monetary values are adjusted to 2019 dollar terms utilizing the Consumer Price Index (CPI) data provided by the Bureau of Labor Statistics (BLS)

NOTES.— The unit of analysis is college-program type and year. The Figures displays yearly number of STEM bachelor's degrees awarded by all 4-year public institutions for four years before and after a maximum cut in state appropriations for each university in the period 2003 to 2019.

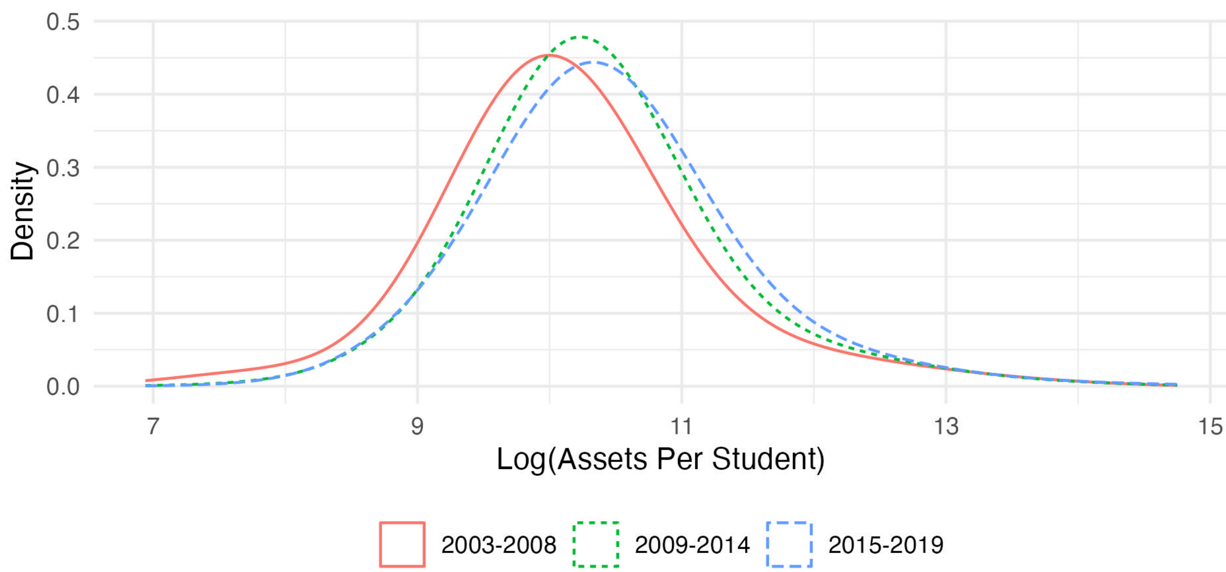
Figure A2: Sensitivity Analysis (DMP, 2022), Breakdown



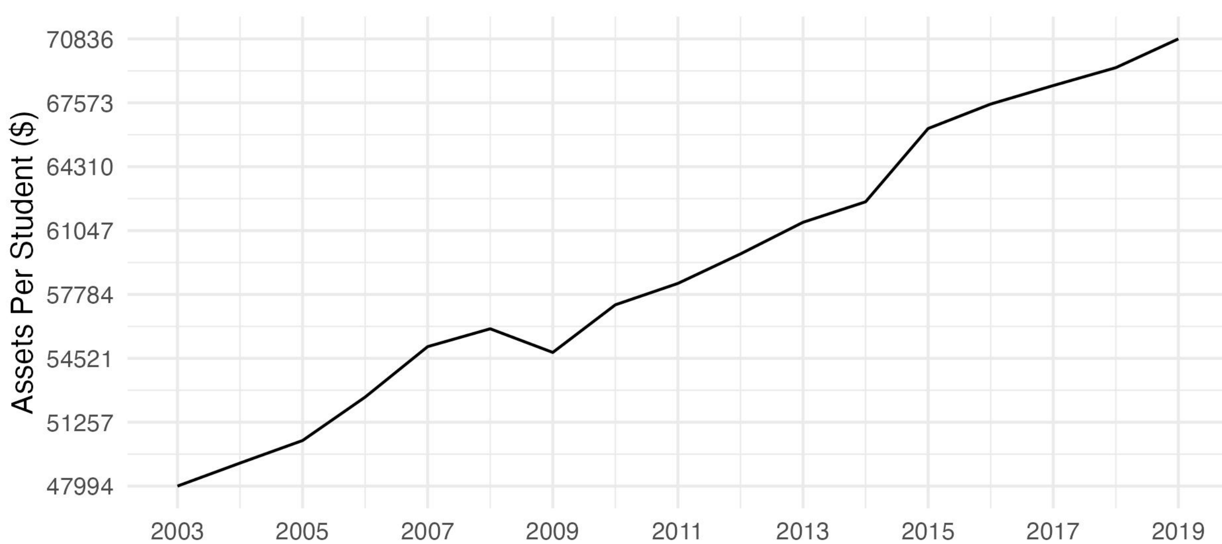
NOTES.— The figures show how the breakdown points ($\bar{r}$), following Diegert et al. (2022), vary with different correlation levels ($\bar{c}$). The title of each subfigure indicates the independent variable and the dependent variable in parentheses, referring to either the number of STEM (Science, Technology, Engineering, and Mathematics) or non-STEM degrees.

Figure A3: Public University Assets Per Student

(a) Density



(b) Average

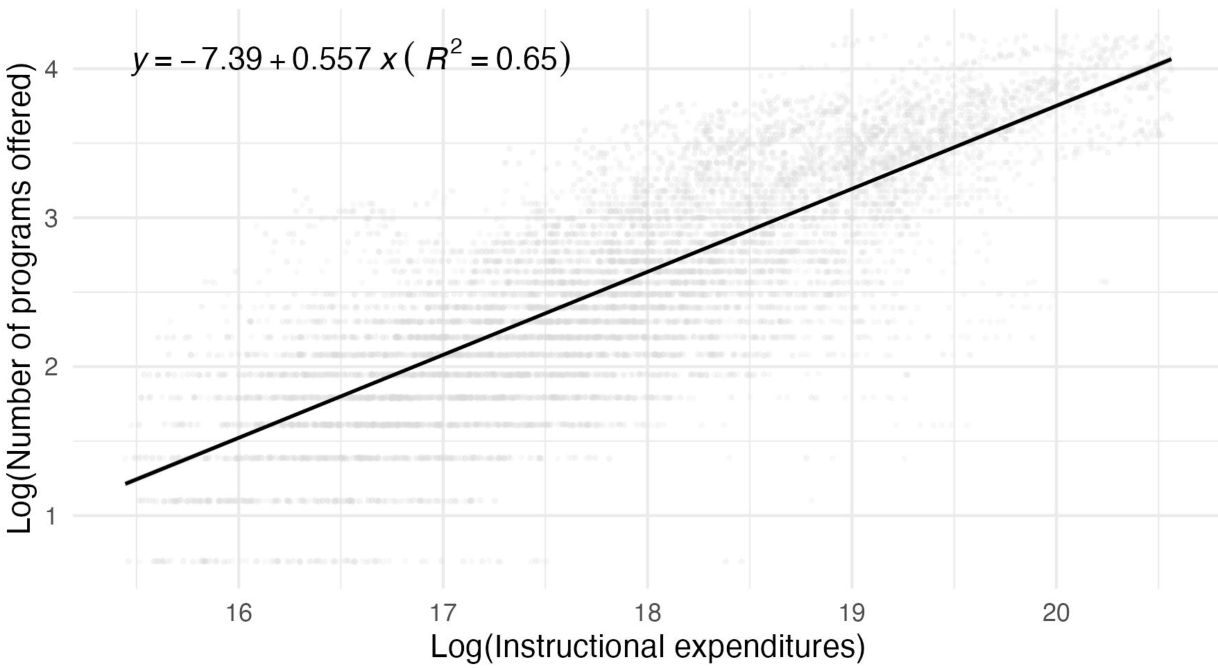


SOURCES.— State Appropriation is extracted from IPEDS finance survey, and universities' headcount or total enrollment from IPEDS 12-Month Enrollment survey.

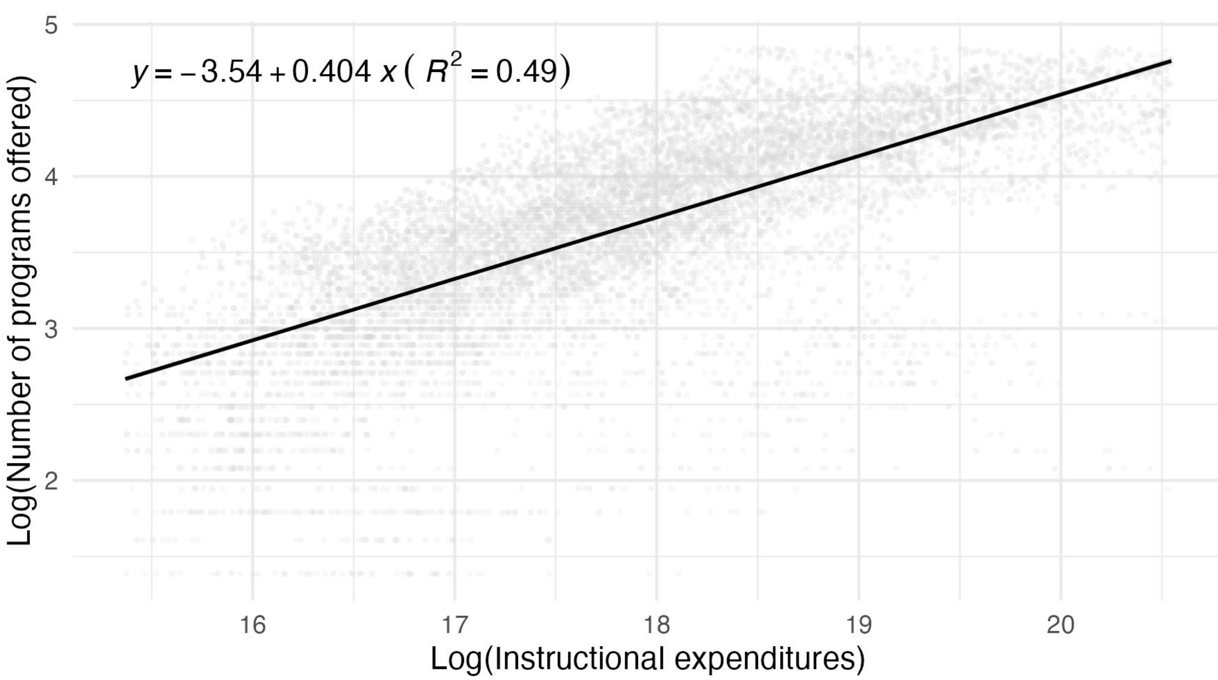
NOTES.— All monetary values are adjusted to 2019 dollar terms utilizing the Consumer Price Index (CPI) data provided by the Bureau of Labor Statistics (BLS). Density plot (a) presents the distribution of log-transformed state appropriations per student. The data spans equally spaced intervals from 2003 to 2019. A kernel density estimate (KDE) is utilized to offer a smooth approximation of the probability density function (PDF). Figure (b) shows the average college assets per student, and tracks its progression over the specified time frame.

Figure A4: Number of Programs Offered vs. Instructional Expenditures, by Programs Type

(a) STEM



(b) Non-STEM



SOURCES.— Instructional Expenditures is extracted from IPEDS finance survey, and number of distinct programs offered is from IPEDS completion survey.

NOTES.— These plots display the relationship between log-transformed instructional expenditures and the log-transformed number of programs offered for STEM (top panel) and non-STEM (bottom panel) institutions. Data points represent individual year-institutions, with jittering applied for visual clarity. The solid line shows the linear fit, with the corresponding equation and R-squared value displayed in the upper left corner of each plot. Both axes are log-scaled. The sample is trimmed to exclude the top and bottom 1% of observations for both variables to mitigate the influence of outliers.

Table A1: Summary Statistics (Full Sample)

	N	Mean	SD
University-Program-Year Level (Program at 6-digit CIP)			
Number of Degrees (Aggregate)			
Total	427,133	42.426	72.345
White	427,133	27.289	44.381
Black	427,133	3.718	9.818
Hispanic	427,133	4.280	15.803
Asian	427,133	3.106	14.276
American Indian	427,133	0.271	1.097
Number of Degrees (Men)			
Men	427,133	18.450	34.586
Men White	427,133	12.112	21.846
Men Black	427,133	1.309	3.479
Men Hispanic	427,133	1.686	6.170
Men Asian	427,133	1.447	7.159
Men American Indian	427,133	0.106	0.489
Number of Degrees (Women)			
Women	427,133	23.976	46.321
Women White	427,133	15.177	29.243
Women Black	427,133	2.409	7.165
Women Hispanic	427,133	2.595	10.841
Women Asian	427,133	1.659	7.851
Women American Indian	427,133	0.165	0.796
University-Year Level			
N Distinct Programs	9,973	67.121	43.363
State Appropriation ($M)	9,973	91.254	114.723
Total Expenditures ($M)	9,973	429.281	763.451
Instructional Expenditures ($M)	9,973	124.185	179.666
Academic Support Expenditures ($M)	9,973	33.734	59.590
Institutional Grants ($M)	9,971	16.828	32.157
Endowment Assets ($M)	9,468	194.044	686.054
Net Price[a]	7,483	12989.120	4063.486
Sticker Price	9,602	7852.819	3032.147
County-Year Level			
Unemployment Rate	8,450	5.834	2.309
Per-capita Personal Income	8,450	39196.304	11903.565
Population	8,450	369946.092	709762.508
Birth Rate	8,450	1196.440	331.174
Death Rate	8,450	819.947	254.754
Share Male Population	8,450	0.493	0.015
Share White Population	8,450	0.805	0.159
Share Black Population	8,450	0.125	0.150
Share Hispanic population	8,450	0.109	0.146
State-Year Level			
State Population (18 to 21)	850	355535.979	394470.157
Per-capita Personal Income	850	42465.868	9268.220
Per 100k SNAP Recipients	850	11578.477	4200.258
Per 100k TANF Recipients	850	1094.994	753.232
Per 100k Medicaid Recipients	850	17707.590	5916.654
Poverty Rate	850	12.612	3.335
State Minimum Wage	850	7.059	1.480
Democratic Governor Dummy	850	0.435	0.496

NOTES.—The unit of analysis is institution-program at the 6-digit CIP (Classification of Instructional Programs) code-year level for the program-level variables. These variables indicate the number of students who graduated in specific majors with bachelor's degrees. The data includes all the programs (STEM and non-STEM) from 2003 to 2019. Other variables are either university-related or pertain to the economic or demographic characteristics of the university's location at the state or county level.

[a] Net Price, which refers to the actual cost of attending college net of any aid or grants, is introduced in IPEDS (Integrated Postsecondary Education Data System) through the Student Financial Aid and Net Price survey beginning from 2007; thus, data for prior years is missing.

Table A2: Summary Statistics–Number of Bachelor Degrees, by Major Type

	Non-STEM (N=351,306)		STEM (N=124,880)		
	Mean	SD	Mean	SD	Diff. in Means
N Distinct Programs [a]	49.626	31.128	18.397	14.893	-31.229***
Number of Degrees:					
Total	40.735	75.351	30.793	49.707	-9.942***
Women	25.111	49.105	11.514	24.814	-13.597***
Men	15.624	33.707	19.279	31.646	3.655***
White	26.489	46.602	19.060	28.953	-7.429***
Black	3.874	10.381	1.843	5.319	-2.031***
Hispanic	4.295	16.688	2.563	8.661	-1.732***
Asian	2.440	13.239	3.763	14.359	1.323***
American Indian	0.272	1.135	0.163	0.716	-0.109***

SOURCES.— The data are extracted from the Integrated Postsecondary Education Data System (IPEDS) Completions Survey, specifically from the subsurvey Awards/Degrees Conferred by Program (6-digit Classification of Instructional Programs/ CIP code), Award Level, Race/Ethnicity, and Gender (U.S. Department of Education, National Center for Education Statistics, 2024).

NOTES.—The unit of analysis is institution-program at the 6-digit CIP code-year level. STEM refers to Science, Technology, Engineering, and Mathematics programs or majors as designated by the Department of Homeland Security (DHS). Table A25 presents the complete list of STEM programs. The table shows the mean difference in the number of bachelor's degrees conferred at 6-digit CIP code between STEM and non-STEM majors. See Table A1 for summary statistics for all variables, including the state and county covariates. Table A3 extends the summary statistics for the number of degrees by providing a breakdown by gender and race. Table A4 presents the same summary statistics but compares different periods.

[a] The number of distinct programs offered is at the institution level.

Table A3: Summary Statistics–Number of Bachelor Degrees, by Major Type, Gender and Race

	Non-STEM (N=351,306)		STEM (N=124,880)		
	Mean	SD	Mean	SD	Diff. in Means
Number of Degrees (Men)					
White	10.396	21.411	12.295	19.738	1.899***
Black	1.257	3.486	0.949	2.784	-0.308***
Hispanic	1.509	6.213	1.523	4.755	0.014
Asian	0.976	6.255	2.206	8.053	1.230***
American Indian	0.096	0.466	0.095	0.46	-0.001
Number of Degrees (Women)					
White	16.093	31.229	6.765	13.972	-9.328***
Black	2.616	7.657	0.893	3.24	-1.723***
Hispanic	2.786	11.604	1.04	4.83	-1.746***
Asian	1.464	7.481	1.557	7.372	0.093***
American Indian	0.176	0.844	0.068	0.408	-0.108***

NOTES.— The unit of analysis is institution-program at the 6-digit CIP code-year level. STEM refers to Science, Technology, Engineering, and Mathematics programs or majors as designated by the Department of Homeland Security (DHS). Table A25 presents the complete list of STEM programs. See Table A1 for summary statistics for all variables, including the state and county covariates.

Table A4: Summary Statistics–Number of Bachelor Degrees, by STEM Type and Period

	Panel (a): STEM Degrees					**Panel (b): Non- STEM Degrees**				
	2003 to 2007 (N=33,148)		2015 to 2019 (N=40,805)			2003 to 2007 (N=96,717)		2015 to 2019 (N=111,166)		
	Mean	SD	Mean	SD	Diff. in Means	Mean	SD	Mean	SD	Diff. in Means
Number of Degrees (Aggregate)										
Total	25.431	39.336	37.417	59.898	11.986***	38.244	67.464	41.384	83.295	3.140***
White	16.885	25.215	21.49	32.514	4.605***	26.9	45.248	24.592	47.496	-2.307***
Black	1.665	4.853	2.126	6.196	0.461***	3.434	9.092	4.147	11.477	0.713***
Hispanic	1.388	4.486	4.077	12.258	2.689***	2.82	11.134	5.894	22.144	3.074***
Asian	2.981	12.186	4.694	15.945	1.713***	2.251	13.468	2.491	13.282	0.239***
American Indian	0.174	0.706	0.14	0.681	-0.034***	0.306	1.274	0.207	0.907	-0.100***
Number of Degrees (Men)										
Total	16.121	26.078	23.162	38.552	7.041***	14.537	30.853	15.672	35.958	1.136***
White	11.021	17.686	13.663	22.174	2.642***	10.443	21.258	9.53	20.876	-0.913***
Black	0.828	2.476	1.118	3.391	0.290***	1.064	3.096	1.377	3.755	0.314***
Hispanic	0.83	2.609	2.402	6.658	1.572***	0.985	3.92	2.057	8.32	1.072***
Asian	1.768	7.111	2.758	9.378	0.990***	0.877	6.015	0.978	6.255	0.101***
American Indian	0.101	0.458	0.081	0.423	-0.019***	0.106	0.508	0.072	0.379	-0.034***
Number of Degrees (Women)										
Total	9.31	18.88	14.255	29.734	4.944***	23.707	42.979	25.712	55.61	2.005***
White	5.863	11.806	7.827	15.769	1.964***	16.456	29.515	15.063	32.981	-1.394***
Black	0.837	2.917	1.008	3.687	0.172***	2.371	6.62	2.77	8.545	0.399***
Hispanic	0.558	2.395	1.674	6.935	1.117***	1.835	8.056	3.837	15.252	2.003***
Asian	1.213	6.102	1.936	7.941	0.723***	1.374	7.831	1.513	7.568	0.139***
American Indian	0.073	0.395	0.059	0.412	-0.014***	0.2	0.954	0.134	0.668	-0.066***

NOTES.—The unit of analysis is institution-program at the 6-digit CIP code-year level. The table shows the mean difference in the number of degrees between two periods for STEM degrees in panel (a) and for non-STEM degrees in panel (b). STEM refers to Science, Technology, Engineering, and Mathematics programs or majors as designated by the Department of Homeland Security (DHS). Table A25 presents the complete list of STEM programs. See Table A1 for summary statistics for all variables, including the state and county covariates.

Table A5: OLS Estimates of the Effect of State Appropriations on Bachelor's Degrees by STEM Type

	Dependent Variable: Log Number of Bachelor Degrees					
	t+4		t+5		t+6	
Panel (a): STEM						
Log State Appropriations	0.192**	0.206***	0.171**	0.177**	0.101	0.106
	(0.079)	(0.078)	(0.083)	(0.081)	(0.079)	(0.077)
Observations	85,574	84,262	77,206	76,019	69,228	68,157
Adj. R2	0.272	0.271	0.275	0.274	0.275	0.274
Panel (b): Non-STEM						
Log State Appropriations	0.199**	0.178**	0.145*	0.124	0.125*	0.105
	(0.083)	(0.081)	(0.078)	(0.075)	(0.073)	(0.071)
Observations	238,383	235,340	214,454	211,681	191,533	189,026
Adj. R2	0.301	0.301	0.299	0.299	0.297	0.297
Institution FE	✓	✓	✓	✓	✓	✓
Program FE (6-Digit CIP)	✓	✓	✓	✓	✓	✓
Year FE	✓	✓	✓	✓	✓	✓
State Controls	✓	✓	✓	✓	✓	✓
County Controls	×	✓	×	✓	×	✓

NOTES.—Each panel and cell refers to a separate OLS regression. The outcome variable in panel (a) is the logged number of undergraduate Science, Technology, Engineering, and Mathematics (STEM) degrees (bachelor's) conferred. In panel (b), the dependent variable is the logged number of non-STEM bachelor's degrees. A lead of "t+i" (ranging from 3 to 6) indicates the ith lead of the outcome variable. For example, the lead t+6 refers to the student cohort that completes bachelor's education in 6 years. CIP refers to the Classification of Instructional Programs, which is used to categorize degree programs by specific majors (see Table A25 for the subset of STEM majors). The unit of analysis is at the institution, program (6-digit CIP), and year level. The models include year, program, and institution fixed effects, as well as time-varying county and state covariates. The state-level controls include poverty rate, logged population aged 18 to 24, per-capita personal income, minimum wage, number of Supplemental Nutrition Assistance Program (SNAP) recipients per 100,000 population, and number of Temporary Assistance for Needy Families (TANF) recipients per 100,000 population. The county-level controls include logged per-capita personal income, total population, unemployment rate, percentage of population by race (Hispanic, Black, and White), percentage of male population, and birth and death rates per 100,000 population. Standard errors are clustered at the institution level. *p < 0.10, **p < 0.05, ***p < 0.01

Table A6: The Effect of State Appropriations on Bachelor's Degrees, by STEM Type–Additional Fixed Effects

	Dependent Variable: Log Number of Bachelor Degrees							
	t+3		t+4		t+5		t+6	
Panel (a): STEM								
Log State Appropriations	0.172	0.252**	0.341**	0.260**	0.297**	0.203**	0.235**	0.176**
	(0.176)	(0.126)	(0.169)	(0.115)	(0.130)	(0.090)	(0.108)	(0.082)
Observations	92,804	92,804	84,262	84,262	76,019	76,019	68,157	68,157
Adj. R2	0.257	0.596	0.157	0.590	0.185	0.627	0.221	0.645
F-test (1st stage)	99.742	105.55	114.24	114.96	182.92	168.69	171.02	157.24
Panel (b): Non-STEM								
Log State Appropriations	0.171	0.248	0.206	0.180	0.188*	0.129	0.142	0.099
	(0.219)	(0.153)	(0.170)	(0.116)	(0.111)	(0.082)	(0.091)	(0.070)
Observations	259,969	259,969	235,340	235,340	211,681	211,681	189,026	189,026
Adj. R2	0.301	0.641	0.293	0.659	0.294	0.670	0.301	0.676
F-test (1st stage)	260.50	262.12	363.31	321.88	632.93	534.53	583.50	486.94
Institution FE	✓	✓	✓	✓	✓	✓	✓	✓
Program FE (6-Digit CIP)	✓	✓	✓	✓	✓	✓	✓	✓
Year FE	✓	✓	✓	✓	✓	✓	✓	✓
Institution-by-program FE	×	✓	×	✓	×	✓	×	✓
Program-by-year FE	×	✓	×	✓	×	✓	×	✓
State Controls	✓	✓	✓	✓	✓	✓	✓	✓
County Controls	×	✓	×	✓	×	✓	×	✓

NOTES.—Each panel and cell refers to a separate 2SLS regression. The outcome variable in panel (a) is the logged number of undergraduate Science, Technology, Engineering, and Mathematics (STEM) degrees (bachelor's) conferred. In panel (b), the dependent variable is the logged number of non-STEM bachelor's degrees. A lead of "t+i" (ranging from 3 to 6) indicates the ith lead of the outcome variable. For example, the lead t+6 refers to the student cohort that completes bachelor's education in 6 years. CIP refers to the Classification of Instructional Programs, which is used to categorize degree programs by specific majors (see Table A25 for the subset of STEM majors). The unit of analysis is at the institution, program (6-digit CIP), and year level. The models include year, program, and institution fixed effects, as well as time-varying county and state covariates. The state-level controls include poverty rate, logged population aged 18 to 24, per-capita personal income, minimum wage, number of Supplemental Nutrition Assistance Program (SNAP) recipients per 100,000 population, and number of Temporary Assistance for Needy Families (TANF) recipients per 100,000 population. The county-level controls include logged per-capita personal income, total population, unemployment rate, percentage of population by race (Hispanic, Black, and White), percentage of male population, and birth and death rates per 100,000 population. Standard errors are clustered at the institution level. *p < 0.10, **p < 0.05, ***p < 0.01

Table A7: The Effect of State Appropriations on Master's Degrees, by STEM Type

	t+1		t+2		t+3		t+4	
	Dependent Variable: Log Number of STEM Master's Degrees							
Log State Appropriations	0.621	0.628	0.782	0.826	0.572**	0.651*	0.573**	0.704*
	(0.465)	(0.536)	(0.640)	(0.765)	(0.281)	(0.357)	(0.272)	(0.365)
Observations	76,970	75,657	69,958	68,751	63,461	62,356	57,373	56,364
F-test (1st stage)	49.79	46.78	38.34	35.75	93.19	79.92	73.48	54.99
	Dependent Variable: Log Number of Non-STEM Master's Degrees							
Log State Appropriations	0.365	0.338	0.378	0.377	0.341	0.349	0.335	0.348
	(0.373)	(0.499)	(0.366)	(0.486)	(0.257)	(0.304)	(0.246)	(0.292)
Observations	187,548	184,639	170,021	167,351	153,629	151,184	138,131	135,916
F-test (1st stage)	95.17	57.14	87.58	52.49	197.80	143.41	208.18	145.24
Institution FE	✓	✓	✓	✓	✓	✓	✓	✓
Program FE (6-Digit CIP)	✓	✓	✓	✓	✓	✓	✓	✓
Year FE	✓	✓	✓	✓	✓	✓	✓	✓
State Controls	✓	✓	✓	✓	✓	✓	✓	✓
County Controls	×	✓	×	✓	×	✓	×	✓

NOTES.—Each panel refers to a separate 2SLS regression. The outcome variable in panel (a) is the logged number of graduate Science, Technology, Engineering, and Mathematics (STEM) degrees (Master's) conferred. In panel (b), the dependent variable is the logged number of non-STEM Master's degrees. A lead of "t+i" (ranging from 3 to 6) indicates the ith lead of the outcome variable. For example, the lead t+3 refers to the student cohort that completes Master's education in 3 years. CIP refers to the Classification of Instructional Programs, which is used to categorize degree programs by specific majors (see Table A25 for the subset of STEM majors). The unit of analysis is at the institution, program (6-digit CIP), and year level. The models include year, program, and institution fixed effects, as well as time-varying county and state covariates. The state-level controls include poverty rate, logged population aged 18 to 24, per-capita personal income, minimum wage, number of Supplemental Nutrition Assistance Program (SNAP) recipients per 100,000 population, and number of Temporary Assistance for Needy Families (TANF) recipients per 100,000 population. The county-level controls include logged per-capita personal income, total population, unemployment rate, percentage of population by race (Hispanic, Black, and White), percentage of male population, and birth and death rates per 100,000 population. Standard errors are clustered at the institution level. *p < 0.10, **p < 0.05, ***p < 0.01

Table A8: The Effect of State Appropriations on Doctor's Degrees, by STEM Type

	t+3		t+4		t+5		t+6	
	Dependent Variable: Log Number of STEM Doctor's Degrees							
Log State Appropriations	0.305	0.211	0.254	0.178	0.356	0.355	-0.022	-0.216
	(0.261)	(0.267)	(0.240)	(0.262)	(0.286)	(0.367)	(0.162)	(0.297)
Observations	40,074	39,122	36,233	35,359	32,517	31,724	29,033	28,319
F-test (1st stage)	56.06	44.71	44.79	33.21	43.98	26.49	43.74	22.39
	Dependent Variable: Log Number of Non-STEM Doctor's Degrees							
Log State Appropriations	0.407	0.297	0.335	0.296	0.257	0.230	0.333	0.308
	(0.318)	(0.342)	(0.267)	(0.306)	(0.194)	(0.204)	(0.235)	(0.238)
Observations	45,302	44,338	40,568	39,709	35,990	35,225	31,625	30,946
F-test (1st stage)	69.72	49.54	83.16	49.77	144.53	88.37	132.08	82.03
Institution FE	✓	✓	✓	✓	✓	✓	✓	✓
Program FE (6-Digit CIP)	✓	✓	✓	✓	✓	✓	✓	✓
Year FE	✓	✓	✓	✓	✓	✓	✓	✓
State Controls	✓	✓	✓	✓	✓	✓	✓	✓
County Controls	×	✓	×	✓	×	✓	×	✓

Note: NOTES.—Each panel refers to a separate 2SLS regression. The outcome variable in panel (a) is the logged number of graduate Science, Technology, Engineering, and Mathematics (STEM) degrees (Doctor's) conferred. In panel (b), the dependent variable is the logged number of non-STEM Doctor's degrees. A lead of "t+i" (ranging from 3 to 6) indicates the ith lead of the outcome variable. For example, the lead t+6 refers to the student cohort that completes Doctor's education in 6 years. CIP refers to the Classification of Instructional Programs, which is used to categorize degree programs by specific majors (see Table A25 for the subset of STEM majors). The unit of analysis is at the institution, program (6-digit CIP), and year level. The models include year, program, and institution fixed effects, as well as time-varying county and state covariates as described in Table A7. *p < 0.10, **p < 0.05, ***p < 0.01

Table A9: The Effect of State Appropriations on Spending

	t+0		t+1		t+2		t+3	
	Dependent Variable (a): Log Total Expenditures							
Log State Appropriations	0.130***	0.122***	0.105***	0.101***	0.066***	0.062***	0.041**	0.036**
	(0.033)	(0.032)	(0.026)	(0.025)	(0.023)	(0.022)	(0.019)	(0.018)
N Institutions	663	663	663	663	663	663	663	663
Observations	9,914	9,742	9,248	9,086	8,599	8,447	7,966	7,824
F-test (1st stage)	27.63	25.16	29.34	26.89	28.18	26.31	34.31	33.03
	Dependent Variable (b): Log Total Instructional Expenditures							
Log State Appropriations	0.186***	0.187***	0.156***	0.158***	0.102***	0.102***	0.063***	0.062***
	(0.046)	(0.047)	(0.037)	(0.037)	(0.030)	(0.029)	(0.023)	(0.022)
N Institutions	663	663	663	663	663	663	663	663
Observations	9,914	9,742	9,248	9,086	8,599	8,447	7,966	7,824
F-test (1st stage)	27.63	25.16	29.34	26.89	28.18	26.31	34.31	33.03
	Dependent Variable (c): Log Academic Support Expenditures							
Log State Appropriations	0.272***	0.274***	0.221***	0.224***	0.164***	0.164***	0.120***	0.116***
	(0.067)	(0.069)	(0.054)	(0.053)	(0.046)	(0.045)	(0.037)	(0.035)
N Institutions	663	663	663	663	663	663	663	663
Observations	9,914	9,742	9,248	9,086	8,599	8,447	7,966	7,824
F-test (1st stage)	27.63	25.16	29.34	26.89	28.18	26.31	34.31	33.03
	Dependent Variable (d): Log Total Institutional Grant Aid							
Log State Appropriations	0.235*	0.284**	0.252*	0.320**	0.258**	0.314**	0.253**	0.286**
	(0.138)	(0.140)	(0.129)	(0.132)	(0.126)	(0.129)	(0.112)	(0.112)
N Institutions	663	663	663	663	663	663	663	663
Observations	9,204	9,047	8,604	8,456	8,013	7,875	7,444	7,316
F-test (1st stage)	24.67	22.19	25.33	22.86	23.87	22.14	30.36	28.83
Institution FE	✓	✓	✓	✓	✓	✓	✓	✓
Year FE	✓	✓	✓	✓	✓	✓	✓	✓
State Controls	✓	✓	✓	✓	✓	✓	✓	✓
County Controls	×	✓	×	✓	×	✓	×	✓

NOTES.—Each panel and cell refers to a separate 2SLS regression. "Academic Support Expenditures" includes spending on tutoring, advising, mentoring, and other expenses related to activities and services that support the institution's primary missions. The models include year and institution fixed effects, as well as time-varying county and state covariates, as described in Table 2. A lead of "t+i" (ranging from 0 to 3) indicates the ith lead of the outcome variable. The unit of analysis is at the institution and year level. Standard errors are clustered at the institution level. *p < 0.10, **p < 0.05, ***p < 0.01

Table A10: The Effect of State Appropriations on Number of Programs Offered

	t+0		t+1		t+2		t+3	
	Dependent Variable (a): Log N Distinct STEM Programs							
Log State appropriations	0.121***	0.126***	0.111***	0.117***	0.084***	0.089***	0.054**	0.058**
	(0.036)	(0.038)	(0.031)	(0.032)	(0.028)	(0.028)	(0.022)	(0.022)
N Institutions	617	617	617	617	617	617	617	617
Observations	9,228	9,061	8,679	8,521	8,129	7,980	7,577	7,437
F-test (1st stage)	25.16	22.52	26.79	24.20	25.64	23.47	32.06	30.33
	Dependent Variable (b): Log N Distinct Non-STEM Programs							
Log State Appropriations	0.071***	0.079***	0.071***	0.078***	0.056***	0.063***	0.037**	0.041**
	(0.026)	(0.027)	(0.023)	(0.024)	(0.021)	(0.022)	(0.017)	(0.017)
N Institutions	663	663	663	663	663	663	663	663
Observations	9,914	9,742	9,248	9,086	8,599	8,447	7,966	7,824
F-test (1st stage)	27.63	25.16	29.34	26.89	28.18	26.31	34.31	33.03
Institution FE	✓	✓	✓	✓	✓	✓	✓	✓
Year FE	✓	✓	✓	✓	✓	✓	✓	✓
State Controls	✓	✓	✓	✓	✓	✓	✓	✓
County Controls	×	✓	×	✓	×	✓	×	✓

NOTES.—Each panel and cell refers to a separate 2SLS regression. "N Distinct STEM/Non-STEM Programs" refers to the institution-level number of distinct programs offered within Science, Technology, Engineering, and Mathematics (STEM) or otherwise (non-STEM). The models include year and institution fixed effects, as well as time-varying county and state covariates, as described in Table 2. A lead of "t+i" (ranging from 0 to 3) indicates the ith lead of the outcome variable. The unit of analysis is at the institution and year level. Standard errors are clustered at the institution level. *p < 0.10, **p < 0.05, ***p < 0.01

Table A11: OLS Estimates for the Effect of Program Offers, Spending, and Prices on Number of Bachelor Degrees

Dept. var.	Log Number of STEM Degrees			Log Number of Non-STEM Degrees		
	t+4	t+5	t+6	t+4	t+5	t+6
Panel (a)						
Log N Distinct Programs	0.171***	0.129***	0.127***	0.066	0.021	-0.019
	(0.041)	(0.034)	(0.035)	(0.045)	(0.052)	(0.045)
Observations	6779	6226	5680	7209	6613	6015
Sensitivity analysis (Diegert et al., 2022)						
$\hat{r}_X^{bp}(\%)$	80.16	79.99	79.64	81.97	81.74	81.46
Panel (b)						
Log Total Expenditures	0.285***	0.227***	0.153***	0.174***	0.102**	0.024
	(0.055)	(0.058)	(0.053)	(0.050)	(0.051)	(0.050)
Observations	6785	6231	5683	7209	6613	6015
Sensitivity analysis (Diegert et al., 2022)						
$\hat{r}_X^{bp}(\%)$	73.72	73.58	73.15	72.85	72.88	72.63
Panel (c)						
Log Academic Support Expenditures	0.124***	0.106***	0.103***	0.039*	0.029	0.011
	(0.030)	(0.029)	(0.028)	(0.023)	(0.021)	(0.021)
Observations	6785	6231	5683	7209	6613	6015
Sensitivity analysis (Diegert et al., 2022)						
$\hat{r}_X^{bp}(\%)$	71.83	71.67	71.39	75.88	75.79	75.51
Panel (d)						
Log Instructional Expenditures	0.263***	0.206***	0.149***	0.115***	0.062	0.016
	(0.047)	(0.050)	(0.051)	(0.039)	(0.039)	(0.037)
Observations	6785	6231	5683	7209	6613	6015
Sensitivity analysis (Diegert et al., 2022)						
$\hat{r}_X^{bp}(\%)$	32.12	32.04	31.80	36.86	36.76	36.52
Panel (e)						
Log Institutional Grants	0.037***	0.023**	0.019**	0.010	0.005	0.003
	(0.009)	(0.009)	(0.009)	(0.008)	(0.008)	(0.008)
Observations	6784	6230	5682	7208	6612	6014
Sensitivity analysis (Diegert et al., 2022)						
$\hat{r}_X^{bp}(\%)$	63.84	63.40	62.98	60.08	59.33	58.34
Panel (f)						
Log Sticker Price	-0.134***	-0.115**	-0.046	-0.063	-0.053	-0.008
	(0.052)	(0.052)	(0.052)	(0.046)	(0.049)	(0.049)
Observations	6597	6057	5523	6932	6355	5779
Sensitivity analysis (Diegert et al., 2022)						
$\hat{r}_X^{bp}(\%)$	41.98	41.88	41.74	13.47	13.46	13.74
Panel (g)						
Log Net Price	-0.040	-0.034	0.002	-0.018	-0.001	0.003
	(0.029)	(0.028)	(0.033)	(0.028)	(0.030)	(0.031)
Observations	4593	4054	3527	4871	4295	3725
Sensitivity analysis (Diegert et al., 2022)						
$\hat{r}_X^{bp}(\%)$	37.53	36.98	35.92	7.24	7.75	7.61
N Institutions	663	663	663	617	617	617
Institution FE	✓	✓	✓	✓	✓	✓
Year FE	✓	✓	✓	✓	✓	✓
State Controls	✓	✓	✓	✓	✓	✓
County Controls	✓	✓	✓	✓	✓	✓

NOTES.—Each panel and cell refers to a separate OLS regression. The outcome variable in the first three columns from the left is the logged number of undergraduate Science, Technology, Engineering, and Mathematics (STEM) degrees (bachelor's) conferred. For the last three columns, the dependent variable is the logged number of non-STEM bachelor's degrees. "N Distinct Programs" refers to the institution-level number of distinct programs offered within STEM for the first three columns and within non-STEM for the last three columns. "Academic Support Expenditures" includes spending on tutoring, advising, mentoring, and other expenses related to activities and services that support the institution's primary missions. The models include year and institution fixed effects, as well as time-varying county and state covariates, as described in Table 2. A lead of "t+i" (ranging from 3 to 6) indicates the ith lead of the outcome variable. For example, the lead t+6 refers to the student cohort that completes bachelor's education in 6 years. The unit of analysis is at the institution and year level. Standard errors are clustered at the institution level. *p < 0.10, **p < 0.05, ***p < 0.01

Table A12: The Effect of State Appropriations on Net and Sticker Prices

	t+0		t+1		t+2		t+3	
	Dependent Variable (a): Log Sticker Price							
Log State Appropriations	-0.104***	-0.108***	-0.078***	-0.083***	-0.058***	-0.064***	-0.027**	-0.032**
	(0.029)	(0.030)	(0.022)	(0.022)	(0.018)	(0.019)	(0.013)	(0.013)
N Institutions	663	663	663	663	663	663	663	663
Observations	9,543	9,374	8,909	8,749	8,291	8,141	7,688	7,548
F-test (1st stage)	25.48	23.96	27.43	25.74	26.81	25.59	32.73	32.14
	Dependent Variable (b): Log Net Price							
Log State Appropriations	-0.181***	-0.208***	-0.132***	-0.162***	-0.070**	-0.092**	-0.034	-0.048**
	(0.063)	(0.069)	(0.049)	(0.055)	(0.035)	(0.036)	(0.023)	(0.023)
N Institutions	663	663	663	663	663	663	663	663
Observations	7,429	7,299	7,326	7,195	7,236	7,104	7,154	7,023
F-test (1st stage)	22.18	22.29	19.90	19.33	14.69	15.35	23.66	23.62
Institution FE	✓	✓	✓	✓	✓	✓	✓	✓
Year FE	✓	✓	✓	✓	✓	✓	✓	✓
State Controls	✓	✓	✓	✓	✓	✓	✓	✓
County Controls	×	✓	×	✓	×	✓	×	✓

NOTES.—Each panel and cell refers to a separate 2SLS regression. The models include year and institution fixed effects, as well as time-varying county and state covariates, as described in Table 2. "Sticker Price" refers to the institution's published tuition and fees, whereas "Net Price" refers to the total college attendance cost minus all grants and aid. A lead of "t+i" (ranging from 3 to 6) indicates the ith lead of the outcome variable. For example, the lead t+6 refers to the student cohort that completes bachelor's education in 6 years. The unit of analysis is at the institution and year level. Standard errors are clustered at the institution level. *p < 0.10, **p < 0.05, ***p < 0.01

Table A13: OLS Estimates for the Effect of Program Offers, Spending, and Prices on Bachelor's Degrees (Alternative Sensitivity Analysis)

Dept. var.	Log Number of STEM Degrees			Log Number of Non-STEM Degrees		
	t+4	t+5	t+6	t+4	t+5	t+6
Panel (a)						
Log N Distinct Programs	0.171***	0.129***	0.127***	0.066	0.021	-0.019
	(0.041)	(0.034)	(0.035)	(0.045)	(0.052)	(0.045)
Observations	6779	6226	5680	7209	6613	6015
Sensitivity analysis (Oster, 2019)						
$\hat{\delta}^{bp}_{resid}(\%)$	76.25	75.96	75.29	59.96	59.16	58.75
Panel (b)						
Log Total Expenditures	0.285***	0.227***	0.153***	0.174***	0.102**	0.024
	(0.055)	(0.058)	(0.053)	(0.050)	(0.051)	(0.050)
Observations	6785	6231	5683	7209	6613	6015
Sensitivity analysis (Oster, 2019)						
$\hat{\delta}^{bp}_{resid}(\%)$	62.92	62.80	62.03	58.74	58.76	58.48
Panel (c)						
Log Academic Support Expenditures	0.124***	0.106***	0.103***	0.039*	0.029	0.011
	(0.030)	(0.029)	(0.028)	(0.023)	(0.021)	(0.021)
Observations	6785	6231	5683	7209	6613	6015
Sensitivity analysis (Oster, 2019)						
$\hat{\delta}^{bp}_{resid}(\%)$	62.21	61.85	61.24	66.85	66.48	65.93
Panel (d)						
Log Instructional Expenditures	0.263***	0.206***	0.149***	0.115***	0.062	0.016
	(0.047)	(0.050)	(0.051)	(0.039)	(0.039)	(0.037)
Observations	6785	6231	5683	7209	6613	6015
Sensitivity analysis (Oster, 2019)						
$\hat{\delta}^{bp}_{resid}(\%)$	10.31	10.41	10.47	12.35	12.43	12.45
Panel (e)						
Log Institutional Grants	0.037***	0.023**	0.019**	0.010	0.005	0.003
	(0.009)	(0.009)	(0.009)	(0.008)	(0.008)	(0.008)
Observations	6784	6230	5682	7208	6612	6014
Sensitivity analysis (Oster, 2019)						
$\hat{\delta}^{bp}_{resid}(\%)$	50.86	52.03	54.52	48.76	48.83	49.36
Panel (f)						
Log Sticker Price	-0.134***	-0.115**	-0.046	-0.063	-0.053	-0.008
	(0.052)	(0.052)	(0.052)	(0.046)	(0.049)	(0.049)
Observations	6597	6057	5523	6932	6355	5779
Sensitivity analysis (Oster, 2019)						
$\hat{\delta}^{bp}_{resid}(\%)$	158.72	164.00	171.21	-315.21	-304.42	-282.41
Panel (g)						
Log Net Price	-0.040	-0.034	0.002	-0.018	-0.001	0.003
	(0.029)	(0.028)	(0.033)	(0.028)	(0.030)	(0.031)
Observations	4593	4054	3527	4871	4295	3725
Sensitivity analysis (Oster, 2019)						
$\hat{\delta}^{bp}_{resid}(\%)$	157.61	176.26	164.69	-50.64	-52.71	-71.74
Institution FE	✓	✓	✓	✓	✓	✓
Year FE	✓	✓	✓	✓	✓	✓
State Controls	✓	✓	✓	✓	✓	✓
County Controls	✓	✓	✓	✓	✓	✓

NOTES.—Each panel refers to a separate OLS regression. The outcome variable in the first three columns from the left is the logged number of undergraduate Science, Technology, Engineering, and Mathematics (STEM) degrees (bachelor's) conferred. For the last three columns, the dependent variable is the logged number of non-STEM bachelor's degrees. "N Distinct Programs" refers to the institution-level number of distinct programs offered within STEM for the first three columns and within non-STEM for the last three columns. "Academic Support Expenditures" includes spending on tutoring, advising, mentoring, and other expenses related to activities and services that support the institution's primary missions. The models include year and institution fixed effects, as well as time-varying county and state covariates, as described in Table 2. A lead of "t+i" (ranging from 3 to 6) indicates the ith lead of the outcome variable. For example, the lead t+6 refers to the student cohort that completes bachelor's education in 6 years. The unit of analysis is at the institution and year level. Standard errors are clustered at the institution level. *p < 0.10, **p < 0.05, ***p < 0.01

Table A14: The Effect of State Appropriations on Bachelor's Degrees, by Institution Selectivity and Degree Type

	Dependent Variable: Log Number of Bachelor Degrees					
	STEM			Non-STEM		
	t+4	t+5	t+6	t+4	t+5	t+6
Panel (a): Non-Selective						
Log State Appropriations	0.293*	0.303**	0.260**	0.144	0.174	0.144
	(0.174)	(0.147)	(0.129)	(0.163)	(0.117)	(0.100)
Observations	71,632	64,588	57,893	210,512	189,302	169,013
F-test (1st stage)	95.88	155.87	137.46	327.27	547.92	503.42
Panel (b): Selective						
Log State Appropriations	0.225	0.182	0.105	0.281	0.194	0.090
	(0.178)	(0.154)	(0.113)	(0.298)	(0.204)	(0.139)
Observations	12,630	11,431	10,264	24,828	22,379	20,013
F-test (1st stage)	87.57	72.88	45.97	117.25	143.20	118.65
N Institutions	663	663	663	617	617	617
N Programs	339	339	339	783	783	783
Institution FE	✓	✓	✓	✓	✓	✓
Program FE (6-Digit CIP)	✓	✓	✓	✓	✓	✓
Year FE	✓	✓	✓	✓	✓	✓
State Controls	✓	✓	✓	✓	✓	✓
County Controls	✓	✓	✓	✓	✓	✓

NOTES.—Each panel and cell refers to a separate 2SLS regression. The outcome variable is the logged number of undergraduate degrees (bachelor's) conferred for Science, Technology, Engineering, and Mathematics (STEM) majors in the first three columns and for non-STEM majors in the last three columns. A lead of "t+i" (ranging from 4 to 6) indicates the ith lead of the outcome variable. The models include year, program, and institution fixed effects, as well as time-varying county and state covariates, as described in Table 2. Selectivity is defined based on the Carnegie classification and refers to the institutions that are in the top 20th percentile of selectivity among all baccalaureate institutions with fewer than 20 percent of entering undergraduate transfers. Standard errors are clustered at the institution level. Based on this classification, there are 45 selective 4-year institutions. Table A19 shows similar results based on the selectivity definition of AAU membership or being listed as competitive in Barron's Profiles of American Colleges. *p < 0.10, **p < 0.05, ***p < 0.01

Table A15: The Effect of State Appropriations on Non-STEM Bachelor's Degrees, by Program Type

	Dependent Variable: Log Number of Non-STEM Bachelor Degrees							
	t+3		t+4		t+5		t+6	
Panel (a): Education								
Log State Appropriations	1.483	1.436	1.245	1.147	1.206	1.081	0.705	0.524
	(1.045)	(1.062)	(0.865)	(0.843)	(0.739)	(0.721)	(0.560)	(0.537)
Observations	38,730	38,631	34,910	34,819	31,269	31,190	27,880	27,811
F-test (1st stage)	532.71	502.10	423.43	416.51	384.86	389.95	301.21	311.92
Panel (b): Business, Management, Marketing, and Related Support Services								
Log State Appropriations	0.314	0.358	0.340	0.367	0.201	0.211	0.139	0.150
	(0.331)	(0.323)	(0.266)	(0.254)	(0.179)	(0.164)	(0.153)	(0.138)
Observations	34,122	33,699	31,044	30,653	28,085	27,727	25,226	24,902
F-test (1st stage)	29.28	30.85	43.42	47.90	70.38	80.03	66.75	77.21
Panel (c): Visual and Performing Arts								
Log State Appropriations	-0.057	-0.126	-0.012	-0.073	0.023	-0.065	0.063	-0.019
	(0.253)	(0.278)	(0.210)	(0.226)	(0.154)	(0.163)	(0.143)	(0.147)
Observations	31,390	30,968	28,543	28,151	25,802	25,442	23,151	22,822
F-test (1st stage)	43.49	35.14	57.66	47.67	91.83	78.60	79.36	67.99
Panel (d): Social Sciences								
Log State Appropriations	0.052	0.025	0.015	0.0004	0.078	0.062	0.089	0.069
	(0.128)	(0.129)	(0.103)	(0.106)	(0.073)	(0.073)	(0.072)	(0.071)
Observations	27,934	27,322	25,713	25,146	23,547	23,025	21,409	20,934
F-test (1st stage)	39.53	38.69	54.21	49.92	98.16	90.33	90.71	85.18
Panel (e): Health Professions and Related Programs								
Log State Appropriations	-0.452	-0.419	-0.307	-0.301	-0.101	-0.109	0.177	0.148
	(0.325)	(0.319)	(0.248)	(0.247)	(0.187)	(0.184)	(0.220)	(0.207)
Observations	19,735	19,543	17,187	17,018	14,805	14,659	12,584	12,459
F-test (1st stage)	34.93	38.15	53.23	55.77	82.24	82.92	59.55	59.90
Panel (f): Others								
Log State Appropriations	0.293	0.296	0.369**	0.365*	0.308**	0.291**	0.264**	0.231**
	(0.214)	(0.239)	(0.188)	(0.202)	(0.133)	(0.131)	(0.116)	(0.108)
Observations	110,370	108,795	100,113	98,666	90,192	88,871	80,638	79,441
F-test (1st stage)	124.58	103.90	172.15	143.75	310.19	269.71	282.76	255.29
Institution FE	✓	✓	✓	✓	✓	✓	✓	✓
Program FE (6-Digit CIP)	✓	✓	✓	✓	✓	✓	✓	✓
Year FE	✓	✓	✓	✓	✓	✓	✓	✓
State Controls	✓	✓	✓	✓	✓	✓	✓	✓
County Controls	×	✓	×	✓	×	✓	×	✓

Note: Each panel refers to a separate 2SLS regression and includes a subset of all sub-majors within the given global major 2-digit CIP code. The outcome variable is the logged number of undergraduate degrees (bachelor's) conferred for non-Science, Technology, Engineering, and Mathematics (non-STEM) majors. See Table A22 for the included majors in panel (f). A lead of "t+i" (ranging from 4 to 6) indicates the ith lead of the outcome variable. The models include year, program, and institution fixed effects, as well as time-varying county and state covariates, as described in Table 2. Standard errors are clustered at the institution level. *p < 0.10, **p < 0.05, ***p < 0.01

Table A16: Impact of State Appropriations on Bachelor STEM Degrees by Race and Major (Total)

	Dependent Variable: Log Number of Bachelor Degrees											
	ALL STEM Majors			Engineering			Physical Sciences			Bio. & Biomed.[a]		
	t+4	t+5	t+6	t+4	t+5	t+6	t+4	t+5	t+6	t+4	t+5	t+6
Panel A: White												
Log State Appropriations	0.172	0.204*	0.191*	0.144	0.253	0.192	0.156	0.082	0.034	0.436	0.462*	0.488**
	(0.155)	(0.120)	(0.105)	(0.206)	(0.206)	(0.168)	(0.151)	(0.103)	(0.102)	(0.388)	(0.267)	(0.237)
Panel B: Black												
Log State Appropriations	0.245	0.130	0.130	0.840*	0.583*	0.248	0.378	0.194	0.167	0.327	0.336	0.288
	(0.179)	(0.124)	(0.118)	(0.484)	(0.338)	(0.261)	(0.254)	(0.173)	(0.162)	(0.407)	(0.287)	(0.278)
Panel C: Hispanic												
Log State Appropriations	0.248	0.212	0.013	-0.015	0.337	0.044	0.184	0.226	0.038	0.232	0.065	-0.105
	(0.200)	(0.153)	(0.130)	(0.388)	(0.348)	(0.266)	(0.264)	(0.200)	(0.167)	(0.412)	(0.285)	(0.286)
Panel D: Asian												
Log State Appropriations	0.035	0.141	0.147	0.019	0.296	0.285	-0.073	0.052	-0.108	0.412	0.111	0.261
	(0.184)	(0.140)	(0.129)	(0.313)	(0.277)	(0.244)	(0.195)	(0.145)	(0.147)	(0.443)	(0.293)	(0.289)
Panel E: American Indian												
Log State Appropriations	0.073	0.141	0.209**	-0.024	0.148	0.368*	-0.117	-0.0007	-0.003	0.481	0.496*	0.408
	(0.111)	(0.095)	(0.101)	(0.195)	(0.203)	(0.215)	(0.129)	(0.081)	(0.083)	(0.366)	(0.287)	(0.282)
Observations	84,262	76,019	68,157	16,842	15,282	13,786	16,402	15,003	13,619	13,846	12,494	11,203
F-test (1st stage)	105.10	167.60	159.80	16.01	18.90	22.35	28.88	53.17	50.29	13.64	24.21	21.82
Institution FE	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Program FE (6-Digit CIP)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Year FE	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
State Controls	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
County Controls	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

[a] Bio. & Biomed. stands for Biological and Biomedical Sciences.

Notes: Each cell represents a separate 2SLS regression. The dependent variable is the log number of bachelor degrees. A lead of "t+i" (ranging from 4 to 6) indicates the ith lead of the outcome variable. The models include year, program, and institution fixed effects, as well as time-varying county and state covariates, as described in Table 2. Standard errors, clustered at the institution level, are in parentheses. ✓ indicates the inclusion of the respective fixed effects or controls. *p < 0.10, **p < 0.05, ***p < 0.01

Table A17: Impact of State Appropriations on Bachelor STEM Degrees by Race and Major (Men)

	Dependent Variable: Log Number of Bachelor Degrees											
	ALL STEM Majors			Engineering			Physical Sciences			Bio. & Biomed.[a]		
	t+4	t+5	t+6	t+4	t+5	t+6	t+4	t+5	t+6	t+4	t+5	t+6
Panel A: White												
Log State Appropriations	0.195	0.229*	0.172*	0.164	0.206	0.084	0.035	0.006	0.054	0.587	0.605**	0.334
	(0.154)	(0.124)	(0.102)	(0.208)	(0.192)	(0.140)	(0.175)	(0.122)	(0.116)	(0.373)	(0.271)	(0.222)
Panel B: Black												
Log State Appropriations	0.256	0.187	0.147	0.843*	0.676*	0.356	0.381*	0.168	0.128	0.266	0.221	0.319
	(0.170)	(0.122)	(0.114)	(0.498)	(0.367)	(0.279)	(0.230)	(0.161)	(0.144)	(0.375)	(0.283)	(0.270)
Panel C: Hispanic												
Log State Appropriations	0.246	0.223	0.068	-0.028	0.204	-0.102	0.403	0.325	0.051	0.495	0.279	0.199
	(0.192)	(0.143)	(0.123)	(0.358)	(0.313)	(0.242)	(0.274)	(0.197)	(0.160)	(0.445)	(0.291)	(0.310)
Panel D: Asian												
Log State Appropriations	-0.008	0.142	0.204*	0.022	0.304	0.369	-0.094	0.036	-0.058	0.177	0.230	0.270
	(0.175)	(0.130)	(0.123)	(0.302)	(0.284)	(0.258)	(0.199)	(0.139)	(0.138)	(0.429)	(0.306)	(0.289)
Panel E: American Indian												
Log State Appropriations	0.065	0.130	0.205**	0.068	0.193	0.410*	-0.058	0.018	0.042	0.117	0.106	0.282
	(0.088)	(0.081)	(0.089)	(0.187)	(0.212)	(0.229)	(0.105)	(0.064)	(0.075)	(0.255)	(0.196)	(0.200)
Observations	84,262	76,019	68,157	16,842	15,282	13,786	16,402	15,003	13,619	13,846	12,494	11,203
F-test (1st stage)	105.10	167.60	159.80	16.01	18.90	22.35	28.88	53.17	50.29	13.64	24.21	21.82
Institution FE	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Program FE (6-Digit CIP)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Year FE	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
State Controls	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
County Controls	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

[a] Bio. & Biomed. stands for Biological and Biomedical Sciences.

Notes: Each cell represents a separate 2SLS regression. The dependent variable is the log number of bachelor degrees. A lead of "t+i" (ranging from 4 to 6) indicates the ith lead of the outcome variable. The models include year, program, and institution fixed effects, as well as time-varying county and state covariates. Standard errors, clustered at the institution level, are in parentheses. *p < 0.10, **p < 0.05, ***p < 0.01

Table A18: Impact of State Appropriations on Bachelor STEM Degrees by Race and Major (Women)

	Dependent Variable: Log Number of Bachelor Degrees											
	ALL STEM Majors			Engineering			Physical Sciences			Bio. & Biomed.[a]		
	t+4	t+5	t+6	t+4	t+5	t+6	t+4	t+5	t+6	t+4	t+5	t+6
Panel A: White												
Log State Appropriations	-0.129	-0.044	-0.038	0.207	0.223	0.224	-0.134	-0.106	-0.176	0.179	0.252	0.432*
	(0.170)	(0.118)	(0.106)	(0.291)	(0.275)	(0.237)	(0.217)	(0.159)	(0.150)	(0.371)	(0.262)	(0.251)
Panel B: Black												
Log State Appropriations	0.049	0.022	0.053	0.034	0.024	0.137	0.099	0.090	0.167	0.490	0.356	0.175
	(0.147)	(0.104)	(0.097)	(0.288)	(0.238)	(0.228)	(0.181)	(0.138)	(0.145)	(0.413)	(0.294)	(0.278)
Panel C: Hispanic												
Log State Appropriations	0.031	0.107	-0.042	-0.284	0.309	0.073	-0.026	-0.012	-0.101	0.073	0.019	-0.237
	(0.163)	(0.128)	(0.122)	(0.329)	(0.304)	(0.260)	(0.216)	(0.164)	(0.167)	(0.431)	(0.286)	(0.314)
Panel D: Asian												
Log State Appropriations	0.078	0.094	0.023	0.033	-0.054	-0.192	0.032	0.089	-0.035	0.654	0.376	0.303
	(0.177)	(0.130)	(0.117)	(0.370)	(0.265)	(0.262)	(0.178)	(0.130)	(0.132)	(0.455)	(0.315)	(0.299)
Panel E: American Indian												
Log State Appropriations	0.025	0.037	0.009	-0.128	-0.008	-0.068	-0.060	-0.025	-0.056	0.537*	0.448*	0.162
	(0.067)	(0.051)	(0.050)	(0.126)	(0.077)	(0.098)	(0.082)	(0.065)	(0.061)	(0.323)	(0.245)	(0.228)
Observations	84,262	76,019	68,157	16,842	15,282	13,786	16,402	15,003	13,619	13,846	12,494	11,203
F-test (1st stage)	105.10	167.60	159.80	16.01	18.90	22.35	28.88	53.17	50.29	13.64	24.21	21.82
Institution FE	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Program FE (6-Digit CIP)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Year FE	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
State Controls	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
County Controls	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

[a] Bio. & Biomed. stands for Biological and Biomedical Sciences.

Notes: Each cell represents a separate 2SLS regression. The dependent variable is the log number of bachelor degrees. A lead of "t+i" (ranging from 4 to 6) indicates the ith lead of the outcome variable. The models include year, program, and institution fixed effects, as well as time-varying county and state covariates. Standard errors, clustered at the institution level, are in parentheses. *p < 0.10, **p < 0.05, ***p < 0.01

Table A19: Impact of State Appropriations on Bachelor's Degrees by Institution Selectivity and Degree Type (Alternative Selectivity Definition)

	Dependent Variable: Log Number of Bachelor Degrees					
	STEM			Non-STEM		
	t+4	t+5	t+6	t+4	t+5	t+6
Panel A: Non-Selective						
Log State Appropriations	0.365**	0.293**	0.274**	0.260	0.220*	0.188*
	(0.182)	(0.141)	(0.131)	(0.166)	(0.121)	(0.106)
Observations	68,003	61,331	54,970	202,727	182,291	162,710
F-test (1st stage)	101.61	163.15	143.24	350.29	574.95	526.24
Panel B: Selective						
Log State Appropriations	0.123	0.307	0.105	-0.359	-0.058	-0.279
	(0.271)	(0.328)	(0.190)	(0.779)	(0.318)	(0.267)
Observations	16,259	14,688	13,187	32,613	29,390	26,316
F-test (1st stage)	32.02	28.62	21.56	20.53	45.135	43.43
Institution FE	✓	✓	✓	✓	✓	✓
Program FE (6-Digit CIP)	✓	✓	✓	✓	✓	✓
Year FE	✓	✓	✓	✓	✓	✓
State Controls	✓	✓	✓	✓	✓	✓
County Controls	✓	✓	✓	✓	✓	✓

Notes: Each panel and cell represent a separate 2SLS regression. The dependent variable is the log number of bachelor's degrees conferred for STEM majors in the first three columns and for non-STEM majors in the last three columns. A lead of "t+i" (ranging from 4 to 6) indicates the ith lead of the outcome variable. The models include year, program, and institution fixed effects, as well as time-varying county and state covariates, as described in Table 2. Selectivity is defined based on the membership in the Association of American Universities (AAU) or Barron's Selectivity (competitive universities). Based on this classification, there are 54 selective 4-year institutions. *p < 0.10, **p < 0.05, ***p < 0.01

Table A20: Impact of State Appropriations on Bachelor's Degrees by Institution Doctoral Offering and Degree Type

	Dependent Variable: Log Number of Bachelor Degrees					
	STEM			Non-STEM		
	t+4	t+5	t+6	t+4	t+5	t+6
Panel A: Non-Doctoral Institutions						
Log State Appropriations	0.368**	0.262**	0.238**	0.226	0.189*	0.181*
	(0.167)	(0.113)	(0.102)	(0.144)	(0.107)	(0.100)
Observations	40,057	36,028	32,209	132,885	119,213	106,169
F-test (1st stage)	94.250	168.96	153.91	324.45	578.64	496.91
Panel B: Doctoral Institutions						
Log State Appropriations	0.139	0.254	0.147	-0.047	0.058	-0.059
	(0.295)	(0.279)	(0.208)	(0.349)	(0.217)	(0.169)
Observations	44,205	39,991	35,948	102,455	92,468	82,857
F-test (1st stage)	34.018	41.759	38.514	90.323	133.81	133.33
Institution FE	✓	✓	✓	✓	✓	✓
Program FE (6-Digit CIP)	✓	✓	✓	✓	✓	✓
Year FE	✓	✓	✓	✓	✓	✓
State Controls	✓	✓	✓	✓	✓	✓
County Controls	✓	✓	✓	✓	✓	✓

Notes: Each panel and cell represent a separate 2SLS regression. The dependent variable is the log number of bachelor's degrees conferred for STEM majors in the first three columns and for non-STEM majors in the last three columns. A lead of "t+i" (ranging from 4 to 6) indicates the ith lead of the outcome variable. The models include year, program, and institution fixed effects, as well as time-varying county and state covariates, as described in Table 2. Doctoral institutions are defined by Carnegie classification as either Doctoral/Research Universities–Intensive or Doctoral/Research Universities–Extensive. *p < 0.10, **p < 0.05, ***p < 0.01

Table A21: Impact of State Appropriations on Bachelor's Degrees by Institution Land-Grant Status and Degree Type

	Dependent Variable: Log Number of Bachelor Degrees					
	STEM			Non-STEM		
	t+4	t+5	t+6	t+4	t+5	t+6
Panel A: Non-Land-Grant Institutions						
Log State Appropriations	0.176	0.148*	0.128*	0.110	0.094	0.085
	(0.127)	(0.088)	(0.076)	(0.154)	(0.090)	(0.077)
Observations	60,637	54,635	48,912	189,753	170,522	152,096
F-test (1st stage)	106.36	195.61	175.03	314.10	605.22	539.00
Panel B: Land-Grant Institutions						
Log State Appropriations	1.19**	1.76*	1.46*	0.848	1.38*	0.889
	(0.553)	(0.923)	(0.839)	(0.691)	(0.724)	(0.614)
Observations	23,625	21,384	19,245	45,587	41,159	36,930
F-test (1st stage)	21.626	10.862	8.0561	76.348	44.162	33.367
Institution FE	✓	✓	✓	✓	✓	✓
Program FE (6-Digit CIP)	✓	✓	✓	✓	✓	✓
Year FE	✓	✓	✓	✓	✓	✓
State Controls	✓	✓	✓	✓	✓	✓
County Controls	✓	✓	✓	✓	✓	✓

Notes: Each panel and cell represent a separate 2SLS regression. The dependent variable is the log number of bachelor's degrees conferred for STEM majors in the first three columns and for non-STEM majors in the last three columns. A lead of "t+i" (ranging from 4 to 6) indicates the ith lead of the outcome variable. The models include year, program, and institution fixed effects, as well as time-varying county and state covariates, as described in Table 2. As defined in IPEDS documentation, Land-grant institutions are colleges or universities designated by state legislatures or Congress to receive benefits from the Morrill Acts of 1862 and 1890. These institutions were originally tasked with providing practical education in agriculture, military tactics, mechanic arts, and classical studies to the working class. *p < 0.10, **p < 0.05, ***p < 0.01

Table A22: Frequency of Other Non-STEM Fields

Category	Count
FOREIGN LANGUAGES, LITERATURES, AND LINGUISTICS	23394
COMMUNICATION, JOURNALISM, AND RELATED PROGRAMS	14507
ENGLISH LANGUAGE AND LITERATURE/LETTERS	11770
AREA, ETHNIC, CULTURAL, GENDER, AND GROUP STUDIES	11370
PARKS, RECREATION, LEISURE, AND FITNESS STUDIES	9406
PSYCHOLOGY	8895
HISTORY	8301
LIBERAL ARTS AND SCIENCES, GENERAL STUDIES AND HUMANITIES	8203
PHILOSOPHY AND RELIGIOUS STUDIES	7633
PUBLIC ADMINISTRATION AND SOCIAL SERVICE PROFESSIONS	7277
FAMILY AND CONSUMER SCIENCES/HUMAN SCIENCES	7092
MULTI/INTERDISCIPLINARY STUDIES	7020
HOMELAND SECURITY, LAW ENFORCEMENT, FIREFIGHTING AND RELATED PROTECTIVE SERVICES	6526
AGRICULTURE, AGRICULTURE OPERATIONS, AND RELATED SCIENCES	5426
ARCHITECTURE AND RELATED SERVICES	3471
NATURAL RESOURCES AND CONSERVATION	1993
LEGAL PROFESSIONS AND STUDIES	1275
TRANSPORTATION AND MATERIALS MOVING	828
COMMUNICATIONS TECHNOLOGIES/TECHNICIANS AND SUPPORT SERVICES	742
MECHANIC AND REPAIR TECHNOLOGIES/TECHNICIANS	352
COMPUTER AND INFORMATION SCIENCES AND SUPPORT SERVICES	339
PERSONAL AND CULINARY SERVICES	214
CONSTRUCTION TRADES	186
LIBRARY SCIENCE	152
ENGINEERING TECHNOLOGIES AND ENGINEERING-RELATED FIELDS	93
PRECISION PRODUCTION	63
THEOLOGY AND RELIGIOUS VOCATIONS	32
MILITARY TECHNOLOGIES AND APPLIED SCIENCES	13

Note: The count is based on the number of observations within 6-digit CIP, institution, and year for each shown 2-digit CIP program category.

Table A23: Top 10 Rotemberg Weight for Institutions

Weight	Institution
0.2835	COLORADO STATE UNIVERSITY
0.2172	MESA STATE COLLEGE
0.1940	UNIVERSITY OF COLORADO AT BOULDER
0.1924	METROPOLITAN STATE COLLEGE OF DENVER
0.1924	UNIVERSITY OF NORTHERN COLORADO
0.1904	UNIVERSITY OF COLORADO AT COLORADO SPRINGS
0.1889	ADAMS STATE COLLEGE
0.1882	FORT LEWIS COLLEGE
0.1877	WESTERN STATE COLLEGE OF COLORADO
0.0604	LINCOLN UNIVERSITY

Note: The Rotemberg weights identify the 4-year public institutions that carry the highest weight in the instrument for the identification (Goldsmith-Pinkham et al., 2020). Since the data does not include industries or countries of origin as replications work in Goldsmith-Pinkham et al. (2020), I use similar approach and compute the institution weights as follow: $\alpha_k = \frac{\gamma_k \beta}{\sum_k \gamma_k \beta}$ where α_k refers to the Rotemberg weight for observation k, γ_k to the covariance between the endogenous variable x_k and the instrument z_k, and β to the first-stage coefficient on the Bartik instrument.

Table A24: Impact of State Appropriations on Bachelor's Degrees (Excluding Top 10 Rotemberg Weight Institutions)

	Dependent Variable: Log Number of Bachelor Degrees					
	t+4		t+5		t+6	
Panel (a): STEM						
Log State Appropriations	0.467**	0.504**	0.595**	0.642**	0.459**	0.476**
	(0.232)	(0.256)	(0.240)	(0.273)	(0.207)	(0.235)
Observations	84,193	82,881	75,963	74,776	68,113	67,042
F-test (1st stage)	127.45	104.81	105.04	78.781	110.16	76.334
Panel (a): Non-STEM						
Log State Appropriations	0.290	0.269	0.371*	0.330	0.328*	0.263
	(0.237)	(0.257)	(0.213)	(0.226)	(0.199)	(0.209)
Observations	235,122	232,079	211,523	208,750	188,913	186,406
F-test (1st stage)	789.16	687.35	686.48	590.32	563.23	472.38
Institution FE	✓	✓	✓	✓	✓	✓
Program FE (6-Digit CIP)	✓	✓	✓	✓	✓	✓
Year FE	✓	✓	✓	✓	✓	✓
State Controls	✓	✓	✓	✓	✓	✓
County Controls	×	✓	×	✓	×	✓

NOTES.—Each panel and cell refers to a separate 2SLS regression. The outcome variable in panel (a) is the logged number of undergraduate Science, Technology, Engineering, and Mathem
atics (STEM) degrees (bachelor's) conferred. In panel (b), the dependent variable is the logged number of non-STEM bachelor's degrees. A lead of "t+i" (ranging from 3 to 6) indicates the ith lead of the outcome variable. For example, the lead t+6 refers to the student cohort that completes bachelor's education in 6 years. CIP refers to the Classification of Instructional Programs, which is used to categorize degree programs by specific majors (see Table A25 for the subset of STEM majors). The Table replicates the main findings in Table 2 after omitting the top 10 institutions that have the highest Rotemberg weights shown in Table A23. Standard errors are clustered at the institution level. *p < 0.10, **p < 0.05, ***p < 0.01

Table A25: DHS STEM Designated Degree Programs

CIP Code Two-Digit Series	2010 CIP Code	CIP Code Title
01	01.0308	Agroecology and Sustainable Agriculture.
01	01.0901	Animal Sciences, General.
01	01.0902	Agricultural Animal Breeding.
01	01.0903	Animal Health.
01	01.0904	Animal Nutrition.
01	01.0905	Dairy Science.
01	01.0906	Livestock Management.
01	01.0907	Poultry Science.
01	01.0999	Animal Sciences, Other.
01	01.1001	Food Science.
01	01.1002	Food Technology and Processing.
01	01.1099	Food Science and Technology, Other.
01	01.1101	Plant Sciences, General.
01	01.1102	Agronomy and Crop Science.
01	01.1103	Horticultural Science.
01	01.1104	Agricultural and Horticultural Plant Breeding.
01	01.1105	Plant Protection and Integrated Pest Management.
01	01.1106	Range Science and Management.
01	01.1199	Plant Sciences, Other.
01	01.1201	Soil Science and Agronomy, General.
01	01.1202	Soil Chemistry and Physics.
01	01.1203	Soil Microbiology.
01	01.1299	Soil Sciences, Other.
03	03.0101	Natural Resources/Conservation, General.

Table A25: (continued)

03	03.0103	Environmental Studies.
03	03.0104	Environmental Science.
03	03.0199	Natural Resources Conservation and Research, Other.
03	03.0205	Water, Wetlands, and Marine Resources Management.
03	03.0502	Forest Sciences and Biology.
03	03.0508	Urban Forestry.
03	03.0509	Wood Science and Wood Products/Pulp and Paper Technology.
03	03.0601	Wildlife, Fish and Wildlands Science and Management.
04	04.0902	Architectural and Building Sciences/Technology.
09	09.0702	Digital Communication and Media/Multimedia.
10	10.0304	Animation, Interactive Technology, Video Graphics and Special Effects.
11	11.0101	Computer and Information Sciences, General.
11	11.0102	Artificial Intelligence.
11	11.0103	Information Technology.
11	11.0104	Informatics.
11	11.0199	Computer and Information Sciences, Other.
11	11.0201	Computer Programming/Programmer, General.
11	11.0202	Computer Programming, Specific Applications.
11	11.0203	Computer Programming, Vendor/Product Certification.
11	11.0299	Computer Programming, Other.
11	11.0301	Data Processing and Data Processing Technology/Technician.
11	11.0401	Information Science/Studies.
11	11.0501	Computer Systems Analysis/Analyst.
11	11.0701	Computer Science.
11	11.0801	Web Page, Digital/Multimedia and Information Resources Design.
11	11.0802	Data Modeling/Warehousing and Database Administration.
11	11.0803	Computer Graphics.

Table A25: (continued)

11	11.0804	Modeling, Virtual Environments and Simulation.
11	11.0899	Computer Software and Media Applications, Other.
11	11.0901	Computer Systems Networking and Telecommunications.
11	11.1001	Network and System Administration/Administrator.
11	11.1002	System, Networking, and LAN/WAN Management/Manager.
11	11.1003	Computer and Information Systems Security/Information Assurance.
11	11.1004	Web/Multimedia Management and Webmaster.
11	11.1005	Information Technology Project Management.
11	11.1006	Computer Support Specialist.
11	11.1099	Computer/Information Technology Services Administration and Management, Other.
13	13.0501	Educational/Instructional Technology.
13	13.0601	Educational Evaluation and Research.
13	13.0603	Educational Statistics and Research Methods.
14	14.XXXX	Engineering.
15	15.0000	Engineering Technology, General.
15	15.0101	Architectural Engineering Technology/Technician.
15	15.0201	Civil Engineering Technology/Technician.
15	15.0303	Electrical, Electronic and Communications Engineering. Technology/Technician.
15	15.0304	Laser and Optical Technology/Technician.
15	15.0305	Telecommunications Technology/Technician.
15	15.0306	Integrated Circuit Design.
15	15.0399	Electrical and Electronic Engineering Technologies/Technicians, Other.
15	15.0401	Biomedical Technology/Technician.
15	15.0403	Electromechanical Technology/Electromechanical Engineering Technology.
15	15.0404	Instrumentation Technology/Technician.

Table A25: (continued)

15	15.0405	Robotics Technology/Technician.
15	15.0406	Automation Engineer Technology/Technician.
15	15.0499	Electromechanical and Instrumentation and Maintenance Technologies/Technicians, Other.
15	15.0501	Heating, Ventilation, Air Conditioning and Refrigeration Engineering Technology/Technician.
15	15.0503	Energy Management and Systems Technology/Technician.
15	15.0505	Solar Energy Technology/Technician.
15	15.0506	Water Quality and Wastewater Treatment Management and Recycling Technology/Technician.
15	15.0507	Environmental Engineering Technology/Environmental Technology.
15	15.0508	Hazardous Materials Management and Waste Technology/Technician.
15	15.0599	Environmental Control Technologies/Technicians, Other.
15	15.0607	Plastics and Polymer Engineering Technology/Technician.
15	15.0611	Metallurgical Technology/Technician.
15	15.0612	Industrial Technology/Technician.
15	15.0613	Manufacturing Engineering Technology/Technician
15	15.0614	Welding Engineering Technology/Technician.
15	15.0615	Chemical Engineering Technology/Technician.
15	15.0616	Semiconductor Manufacturing Technology.
15	15.0699	Industrial Production Technologies/Technicians, Other.
15	15.0701	Occupational Safety and Health Technology/Technician.
15	15.0702	Quality Control Technology/Technician.
15	15.0703	Industrial Safety Technology/Technician.
15	15.0704	Hazardous Materials Information Systems Technology/Technician.
15	15.0799	Quality Control and Safety Technologies/Technicians, Other.
15	15.0801	Aeronautical/Aerospace Engineering Technology/Technician.

Table A25: (continued)

15	15.0803	Automotive Engineering Technology/Technician.
15	15.0805	Mechanical Engineering/Mechanical Technology/Technician.
15	15.0899	Mechanical Engineering Related Technologies/Technicians, Other.
15	15.0901	Mining Technology/Technician.
15	15.0903	Petroleum Technology/Technician.
15	15.0999	Mining and Petroleum Technologies/Technicians, Other.
15	15.1001	Construction Engineering Technology/Technician.
15	15.1102	Surveying Technology/Surveying.
15	15.1103	Hydraulics and Fluid Power Technology/Technician.
15	15.1199	Engineering-Related Technologies, Other.
15	15.1201	Computer Engineering Technology/Technician.
15	15.1202	Computer Technology/Computer Systems Technology.
15	15.1203	Computer Hardware Technology/Technician.
15	15.1204	Computer Software Technology/Technician.
15	15.1299	Computer Engineering Technologies/Technicians, Other.
15	15.1301	Drafting and Design Technology/Technician, General.
15	15.1302	CAD/CADD Drafting and/or Design Technology/Technician.
15	15.1303	Architectural Drafting and Architectural CAD/CADD.
15	15.1304	Civil Drafting and Civil Engineering CAD/CADD.
15	15.1305	Electrical/Electronics Drafting and Electrical/Electronics CAD/CADD.
15	15.1306	Mechanical Drafting and Mechanical Drafting CAD/CADD.
15	15.1399	Drafting/Design Engineering Technologies/Technicians, Other.
15	15.1401	Nuclear Engineering Technology/Technician.
15	15.1501	Engineering/Industrial Management.
15	15.1502	Engineering Design.
15	15.1503	Packaging Science.
15	15.1599	Engineering-Related Fields, Other.

Table A25: (continued)

15	15.1601	Nanotechnology.
15	15.9999	Engineering Technologies and Engineering-Related Fields, Other.
26	26.XXXX	Biological and Biomedical Sciences.
27	27.XXXX	Mathematics and Statistics.
28	28.0501	Air Science/Airpower Studies.
28	28.0502	Air and Space Operational Art and Science.
28	28.0505	Naval Science and Operational Studies.
29	29.0201	Intelligence, General.
29	29.0202	Strategic Intelligence.
29	29.0203	Signal/Geospatial Intelligence.
29	29.0204	Command & Control (C3, C4I) Systems and Operations.
29	29.0205	Information Operations/Joint Information Operations.
29	29.0206	Information/Psychological Warfare and Military Media Relations.
29	29.0207	Cyber/Electronic Operations and Warfare.
29	29.0299	Intelligence, Command Control and Information Operations, Other.
29	29.0301	Combat Systems Engineering.
29	29.0302	Directed Energy Systems.
29	29.0303	Engineering Acoustics.
29	29.0304	Low-Observables and Stealth Technology.
29	29.0305	Space Systems Operations.
29	29.0306	Operational Oceanography.
29	29.0307	Undersea Warfare.
29	29.0399	Military Applied Sciences, Other.
29	29.0401	Aerospace Ground Equipment Technology.
29	29.0402	Air and Space Operations Technology.
29	29.0403	Aircraft Armament Systems Technology.
29	29.0404	Explosive Ordinance/Bomb Disposal.

Table A25: (continued)

29	29.0405	Joint Command/Task Force (C3, C4I) Systems.
29	29.0406	Military Information Systems Technology.
29	29.0407	Missile and Space Systems Technology.
29	29.0408	Munitions Systems/Ordinance Technology.
29	29.0409	Radar Communications and Systems Technology.
29	29.0499	Military Systems and Maintenance Technology, Other.
29	29.9999	Military Technologies and Applied Sciences, Other.
30	30.0101	Biological and Physical Sciences.
30	30.0601	Systems Science and Theory.
30	30.0801	Mathematics and Computer Science.
30	30.1001	Biopsychology.
30	30.1701	Behavioral Sciences.
30	30.1801	Natural Sciences.
30	30.1901	Nutrition Sciences.
30	30.2501	Cognitive Science.
30	30.2701	Human Biology.
30	30.3001	Computational Science.
30	30.3101	Human Computer Interaction.
30	30.3201	Marine Sciences.
30	30.3301	Sustainability Studies.
40	40.XXXX	Physical Sciences.
41	41.0000	Science Technologies/Technicians, General.
41	41.0101	Biology Technician/Biotechnology Laboratory Technician.
41	41.0204	Industrial Radiologic Technology/Technician.
41	41.0205	Nuclear/Nuclear Power Technology/Technician.
41	41.0299	Nuclear and Industrial Radiologic Technologies/Technicians, Other.
41	41.0301	Chemical Technology/Technician.

Table A25: (continued)

41	41.0303	Chemical Process Technology.
41	41.0399	Physical Science Technologies/Technicians, Other.
41	41.9999	Science Technologies/Technicians, Other.
42	42.2701	Cognitive Psychology and Psycholinguistics.
42	42.2702	Comparative Psychology.
42	42.2703	Developmental and Child Psychology.
42	42.2704	Experimental Psychology.
42	42.2705	Personality Psychology.
42	42.2706	Physiological Psychology/Psychobiology.
42	42.2707	Social Psychology.
42	42.2708	Psychometrics and Quantitative Psychology.
42	42.2709	Psychopharmacology.
42	42.2799	Research and Experimental Psychology, Other.
43	43.0106	Forensic Science and Technology.
43	43.0116	Cyber/Computer Forensics and Counterterrorism.
45	45.0301	Archeology.
45	45.0603	Econometrics and Quantitative Economics.
45	45.0702	Geographic Information Science and Cartography.
49	49.0101	Aeronautics/Aviation/Aerospace Science and Technology, General.
51	51.1002	Cytotechnology/Cytotechnologist.
51	51.1005	Clinical Laboratory Science/Medical Technology/Technologist.
51	51.1401	Medical Scientist.
51	51.2003	Pharmaceutics and Drug Design.
51	51.2004	Medicinal and Pharmaceutical Chemistry.
51	51.2005	Natural Products Chemistry and Pharmacognosy.
51	51.2006	Clinical and Industrial Drug Development.
51	51.2007	Pharmacoeconomics/Pharmaceutical Economics.

Table A25: (continued)

51	51.2009	Industrial and Physical Pharmacy and Cosmetic Sciences.
51	51.2010	Pharmaceutical Sciences.
51	51.2202	Environmental Health.
51	51.2205	Health/Medical Physics.
51	51.2502	Veterinary Anatomy.
51	51.2503	Veterinary Physiology.
51	51.2504	Veterinary Microbiology and Immunobiology.
51	51.2505	Veterinary Pathology and Pathobiology.
51	51.2506	Veterinary Toxicology and Pharmacology.
51	51.2510	Veterinary Preventive Medicine, Epidemiology, and Public Health.
51	51.2511	Veterinary Infectious Diseases.
51	51.2706	Medical Informatics.
52	52.1301	Management Science.
52	52.1302	Business Statistics.
52	52.1304	Actuarial Science.
52	52.1399	Management Science and Quantitative Methods, Other.

NOTES.—The table lists all the STEM (Science, Technology, Engineering, and Mathematics) programs or majors as designated by the Department of Homeland Security (The U.S. Department of Homeland Security, 2020).

B Background on The Framework

The classic production function for education relates a function of inputs to student achievements, such as degree completion. For instance, the following simple production function demonstrates that student achievement (A^S for STEM related fields and A^{NS} for non-STEM) is a function of various inputs, including expenditures on instruction, academic support, institutional grants, and other factors for both STEM fields (S) and non-STEM majors (NS).[B1]

$$A^j = f(x_1^j, x_2^j, \ldots, x_{n^j}^j) \quad j \in \{S, NS\}$$

This hypothetical production function is then subject to a budget constraint, which requires costs to be less than total revenue from all sources, as illustrated in the following equation:

$$\sum_{k=1}^{m} R_k \geq \sum_{i=1}^{n^S} p_i^S x_i^S + \sum_{i=1}^{n^{NS}} p_i^{NS} x_i^{NS}$$

Where x_i and p_i refer to input and input price, respectively. For example, an input x_1 could be the number of faculty hours, with the corresponding price p_1 being the faculty hourly wage. Similarly, an input x_2 could be the number of academic support staff hours, with the corresponding price p_2 being the academic support hourly wage. Public institutions generate revenue (R_k) from various sources, including local, state, and federal funds, as well as tuition, fees, and individual donations. In fiscal year 2019-20, the top five sources of revenue for 4-year public institutions were tuition and fees (20.29%), state appropriations (16.69%), hospital revenue (15.98%), federal grants and contracts (8.48%), and federal nonoperating grants (4.75%) (National Center for Education Statistics, 2024).[B2]

[B1]Handel and Hanushek (2022) discusses a similar objective function relevant to K-12 education. There are many other possible outputs besides A^j, such as promoting diversity and equity, advancing sustainability and environmental stewardship, and driving innovation through research (Chan, 2016). Additionally, public universities employ a distinctive production technology wherein students act both as customers and as inputs due to the influence of peer effects (Winston, 1999).

[B2]In fiscal year 2007-08, the top five sources of revenue for 4-year public institutions were state appropriations (23.83%), tuition and fees (17.93%), hospital revenue (11.27%), federal grants and contracts (10.51%), and sales and services of auxiliary enterprises (8.28%) (National Center for Education Statistics, 2024).

In this hypothetical scenario, the objective of public institutions is to minimize their costs. The solution involves equalizing the marginal product per dollar of input. The proposed objective function is useful in illustrating that STEM achievement (measured as the number of degrees conferred) may require a different set or a greater quantity of resources than non-STEM majors. For instance, instructional expenditures per student credit hour are 92% higher for electrical engineering than for English-related courses (Hemelt et al., 2021). This implies that different majors (e.g., STEM vs. non-STEM) necessitate different levels of inputs. The engineering department, for example, may require more resources per student than the business or english departments, including additional support for specialized software and laboratory supervision.

The resource-intensive nature of STEM majors motivates the hypothesis that the marginal product of STEM majors exceeds that of non-STEM majors. Consequently, state appropriations may have a more pronounced effect on STEM major completion rates.

C Optimization Problem of a Public 4-Year University

In this section, I develop a model of a college's optimization problem for producing degrees (STEM or Non-STEM). The college aims to maximize the number of degrees produced (Y) through a production function that depends on instruction spending (I), aid spending (D), and academic support spending (S). The production function takes the form of a Cobb-Douglas function with total factor productivity A and output elasticities α, β, and γ for I, D, and S, respectively. The college faces a budget constraint where the sum of these expenditures must not exceed the total available revenue, which consists of state appropriations (R_s) and revenue from non-state sources (R_n).

$$\max_{I,D,S} \quad Y = AI^{\alpha}D^{\beta}S^{\gamma}$$
$$\text{s.t.} \quad I + D + S = R_s + R_n$$

I focus on three spending production inputs (I, S, D) because they are the core expenditures most likely to affect the production of degrees, as highlighted in the literature (Dynarski, 2003, Deming and Walters, 2018, Hinrichs, 2022). I assume that other expenditures such as public service (i.e., non-instructional services to the community), student services (e.g., registrar activities), and auxiliary enterprise expenses (e.g., dining services and bookstores) have minimal to no effect on colleges' ability to convert enrollments into degree completions.[C3]

This formulation allows me to analyze how changes in state funding affect the optimal allocation of resources and, consequently, the production of degrees. By solving this constrained optimization problem using the Lagrangian method as shown in subsection C.1, I derive the following closed-form solutions for the optimal levels of each type of spending and the resulting degree production.

[C3] Appendix B discusses an alternative related objective function that minimizes the cost of production, which is more relevant to K-12 education. It is worth noting that the objective function of public universities is more nuanced, with no consensus in the literature on its precise formulation.

$$Y^* = A(R_s + R_n)^{\alpha+\beta+\gamma} \left(\frac{\alpha^\alpha \beta^\beta \gamma^\gamma}{(\alpha+\beta+\gamma)^{\alpha+\beta+\gamma}} \right) \tag{C.1}$$

The marginal effect of state appropriations on degree production is given by the partial derivative $\frac{\partial Y}{\partial R_s} = (\alpha + \beta + \gamma)\frac{Y}{R_s+R_n}$. This expression decomposes into two components: the sum of output elasticities $(\alpha + \beta + \gamma)$, representing the overall responsiveness of degree production to changes in total resources, and the ratio of current degree production to total revenue $\frac{Y}{R_s+R_n}$. An increase in R_s, ceteris paribus, directly augments total revenue (R_s+R_n), leading to a proportional increase in Y that is $(\alpha+\beta+\gamma)$ times the percentage increase in $(R_s + R_n)$. However, this effect exhibits diminishing marginal returns as the denominator $(R_s + R_n)$ grows with increasing R_s. Despite this, the absolute number of degrees produced (Y) continues to increase with R_s, albeit at a decreasing rate.

The elasticity of Y with respect to R_s is $(\alpha+\beta+\gamma)\frac{R_s}{R_s+R_n}$, implying that when $(\alpha+\beta+\gamma) = 1$, a 1% increase in R_s leads to a $\frac{R_s}{R_s+R_n}\%$ increase in Y. The model allows for various scale effects: if $(\alpha + \beta + \gamma) > 1$, there are increasing returns to scale, amplifying the impact of additional state funding, while $(\alpha + \beta + \gamma) < 1$ implies decreasing returns to scale.

University spending can indirectly increase the number of degrees awarded, particularly in STEM fields. Conversely, reduced spending may limit new program offerings that align with market needs, thereby affecting student persistence and degree completion.

To model the indirect effects of program offerings on degree completion through spending, let $P = \phi I^\theta$. The production function is adjusted to $Y = AI^\alpha D^\beta S^\gamma (\phi I^\theta)^\eta$, where η is the elasticity of output with respect to programs offered, θ is the elasticity of programs with respect to instructional spending, and ϕ is a scaling parameter for the number of programs. Solution steps are detailed in subsection C.2.[C4]

The resultant closed-form is:

[C4] Figure A4 illustrates the strong linear correlation between instructional expenditures and the number of programs, particularly for STEM majors. A limitation of this model is that it does not account for all factors influencing public universities' ability to expand their program offerings (e.g., accreditation requirements, state regulations, and approval processes).

$$Y^* = A\phi^{\eta}(R_s + R_n)^{\alpha+\beta+\gamma+\eta\theta}\left(\frac{(\alpha+\eta\theta)^{\alpha+\eta\theta}\beta^{\beta}\gamma^{\gamma}}{(\alpha+\beta+\gamma+\eta\theta)^{\alpha+\beta+\gamma+\eta\theta}}\right) \tag{C.2}$$

When $\eta = 0$, the model is silent on the number of programs and the reduced form turns back to equation 1. The introduction of program offerings into the production function ($\eta > 0$) yields several important insights. First, it leads to a larger share of resources being allocated to instruction ($\frac{\alpha+\eta\theta}{\alpha+\beta+\gamma+\eta\theta} > \frac{\alpha}{\alpha+\beta+\gamma}$), reflecting the additional benefit of instructional spending through its effect on program diversity. Second, the elasticity of output with respect to total revenue increases ($\alpha + \beta+\gamma+\eta\theta > \alpha+\beta+\gamma$), implying that changes in funding have a more pronounced impact on degree production when program offerings are considered. Finally, the model predicts an amplification effect of instructional spending on output: a 1% increase in instructional expenditure leads to an $(\alpha + \eta\theta)\%$ increase in degree production, rather than just $\alpha\%$.

This framework provides a theoretical foundation for understanding the mechanisms through which state appropriations influence degree completion in public universities, aligning with and informing the empirical analysis in my study. Specifically, I estimate α, β, γ, and η for both STEM and non-STEM production functions and then examine the counterfactual effects of state appropriations in the counterfactual analysis section.

C.1 Optimization solution without indirect effect of number of programs offered

$$\max_{I,D,S} \quad Y = AI^{\alpha}D^{\beta}S^{\gamma} \tag{C.3}$$

$$\text{s.t.} \quad I + D + S = R_s + R_n \tag{C.4}$$

where:

$$\begin{aligned}
Y &= \text{Number of degrees (STEM or Non-STEM) produced} \\
A &= \text{Total factor productivity} \\
I &= \text{Instruction spending} \\
D &= \text{Aid spending (institutional grants)} \\
S &= \text{Academic support spending} \\
R_s &= \text{Revenue from state appropriations} \\
R_n &= \text{Revenue from non-state sources} \\
\alpha, \beta, \gamma &= \text{Output elasticities}
\end{aligned}$$

I form the Lagrangian:

$$\mathcal{L} = AI^{\alpha}D^{\beta}S^{\gamma} + \lambda(R_s + R_n - I - D - S) \tag{C.5}$$

The first-order conditions are:

$$\frac{\partial \mathcal{L}}{\partial I} = \alpha AI^{\alpha-1}D^{\beta}S^{\gamma} - \lambda = 0 \tag{C.6}$$

$$\frac{\partial \mathcal{L}}{\partial D} = \beta AI^{\alpha}D^{\beta-1}S^{\gamma} - \lambda = 0 \tag{C.7}$$

$$\frac{\partial \mathcal{L}}{\partial S} = \gamma AI^{\alpha}D^{\beta}S^{\gamma-1} - \lambda = 0 \tag{C.8}$$

$$\frac{\partial \mathcal{L}}{\partial \lambda} = R_s + R_n - I - D - S = 0 \tag{C.9}$$

From the first three conditions, I can derive:

$$\frac{\alpha Y}{I} = \frac{\beta Y}{D} = \frac{\gamma Y}{S} = \lambda \tag{C.10}$$

This implies:

$$I = \frac{\alpha Y}{\lambda} \tag{C.11}$$

$$D = \frac{\beta Y}{\lambda} \tag{C.12}$$

$$S = \frac{\gamma Y}{\lambda} \tag{C.13}$$

Substituting these into the budget constraint:

$$\frac{\alpha Y}{\lambda} + \frac{\beta Y}{\lambda} + \frac{\gamma Y}{\lambda} = R_s + R_n \tag{C.14}$$

Solving for λ:

$$\lambda = \frac{(\alpha + \beta + \gamma)Y}{R_s + R_n} \tag{C.15}$$

Substituting back, I get the optimal allocation:

$$I^* = \frac{\alpha(R_s + R_n)}{\alpha + \beta + \gamma} \tag{C.16}$$

$$D^* = \frac{\beta(R_s + R_n)}{\alpha + \beta + \gamma} \tag{C.17}$$

$$S^* = \frac{\gamma(R_s + R_n)}{\alpha + \beta + \gamma} \tag{C.18}$$

Substituting these into the production function yields:

$$Y^* = A\left(\frac{\alpha(R_s + R_n)}{\alpha + \beta + \gamma}\right)^{\alpha}\left(\frac{\beta(R_s + R_n)}{\alpha + \beta + \gamma}\right)^{\beta}\left(\frac{\gamma(R_s + R_n)}{\alpha + \beta + \gamma}\right)^{\gamma} \tag{C.19}$$

This can be simplified to:

$$Y^* = A(R_s + R_n)^{\alpha+\beta+\gamma} \left(\frac{\alpha^\alpha \beta^\beta \gamma^\gamma}{(\alpha+\beta+\gamma)^{\alpha+\beta+\gamma}} \right) \tag{C.20}$$

C.2 Optimization solution with indirect effect of number of programs offered

Multiple factors influence public universities' ability to expand their program offerings, including funding and budget constraints, accreditation requirements, and state regulations and approval processes. For simplicity, and based on the observed high correlation between instructional spending and the number of programs offered (see Figure A4), I assume that the number of programs is a function of instructional expenditures and update the college's production function for degrees as follow:

$$Y = AI^\alpha D^\beta S^\gamma P^\eta$$

Substitute $P = \phi I^\theta$ into the production function:

$$Y = AI^\alpha D^\beta S^\gamma (\phi I^\theta)^\eta$$

Simplified updated production function:

$$Y = A\phi^\eta I^{\alpha+\eta\theta} D^\beta S^\gamma$$

Hence the optimization problem becomes:

$$\max_{I,D,S} \quad Y = A\phi^\eta I^{\alpha+\eta\theta} D^\beta S^\gamma \tag{C.21}$$

$$\text{s.t.} \quad I + D + S = R_s + R_n \tag{C.22}$$

where:

$$P = \phi I^{\theta} \quad \text{(Number of programs offered)}$$

$$\eta = \text{Elasticity of output with respect to programs offered}$$

$$\theta = \text{Elasticity of programs with respect to instruction spending}$$

$$\phi = \text{Scaling parameter for the number of programs}$$

All other variables and parameters are as described in the previous optimization.

1) The Lagrangian function is now given by:

$$\mathcal{L} = A\phi^{\eta} I^{\alpha+\eta\theta} D^{\beta} S^{\gamma} + \lambda(R_s + R_n - I - D - S)$$

2) First-order conditions: differentiating the Lagrangian with respect to I, D, S, and λ:

$$\frac{\partial \mathcal{L}}{\partial I} = A\phi^{\eta}(\alpha + \eta\theta) I^{\alpha+\eta\theta-1} D^{\beta} S^{\gamma} - \lambda = 0 \tag{C.23}$$

$$\frac{\partial \mathcal{L}}{\partial D} = A\phi^{\eta}\beta I^{\alpha+\eta\theta} D^{\beta-1} S^{\gamma} - \lambda = 0 \tag{C.24}$$

$$\frac{\partial \mathcal{L}}{\partial S} = A\phi^{\eta}\gamma I^{\alpha+\eta\theta} D^{\beta} S^{\gamma-1} - \lambda = 0 \tag{C.25}$$

$$\frac{\partial \mathcal{L}}{\partial \lambda} = R_s + R_n - I - D - S = 0 \tag{C.26}$$

3) Solving for optimal allocations: from the first-order conditions, we can derive:

$$\frac{(\alpha + \eta\theta)Y}{I} = \frac{\beta Y}{D} = \frac{\gamma Y}{S} = \lambda \tag{C.27}$$

This implies:

$$D = \frac{\beta I}{(\alpha + \eta\theta)} \tag{C.28}$$

$$S = \frac{\gamma I}{(\alpha + \eta\theta)} \tag{C.29}$$

Substituting these into the budget constraint:

$$I + \frac{\beta I}{(\alpha + \eta\theta)} + \frac{\gamma I}{(\alpha + \eta\theta)} = R_s + R_n \tag{C.30}$$

Solving for I:

$$I = \frac{(\alpha + \eta\theta)(R_s + R_n)}{(\alpha + \beta + \gamma + \eta\theta)} \tag{C.31}$$

And consequently:

$$D = \frac{\beta(R_s + R_n)}{(\alpha + \beta + \gamma + \eta\theta)} \tag{C.32}$$

$$S = \frac{\gamma(R_s + R_n)}{(\alpha + \beta + \gamma + \eta\theta)} \tag{C.33}$$

4) Substituting these optimal allocations back into the production function:

$$Y^* = A\phi^\eta \left(\frac{(\alpha + \eta\theta)(R_s + R_n)}{(\alpha + \beta + \gamma + \eta\theta)}\right)^{\alpha+\eta\theta} \left(\frac{\beta(R_s + R_n)}{(\alpha + \beta + \gamma + \eta\theta)}\right)^{\beta} \left(\frac{\gamma(R_s + R_n)}{(\alpha + \beta + \gamma + \eta\theta)}\right)^{\gamma} \tag{C.34}$$

This can be simplified to:

$$Y^* = A\phi^\eta (R_s + R_n)^{\alpha+\beta+\gamma+\eta\theta} \left(\frac{(\alpha + \eta\theta)^{\alpha+\eta\theta}\beta^\beta\gamma^\gamma}{(\alpha + \beta + \gamma + \eta\theta)^{\alpha+\beta+\gamma+\eta\theta}}\right) \tag{C.35}$$