Promise kept? Free community college, attainment, and earnings in Tennessee[1]

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WORK IN PROGRESS

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Abstract

We examine the effect of a local "free community college" program on college credit accumulation, completion, and short-term labor market outcomes. Knox Achieves pledged tuition-free community college to any Knox County, Tennessee high school graduate and served as the model for the statewide Tennessee Promise program as well as a growing number of state initiatives across the U.S. We find that Knox Achieves eligibility or participation led to a higher likelihood of attaining a two-year college credential alongside heterogeneous changes in the likelihood of attaining a bachelor's degree. Eligible higher-achieving students, some of whom may have been swayed to start at a community college rather than a four-year school, were less likely to complete a bachelor's degree after the introduction of Knox Achieves, particularly if they were economically disadvantaged. Lower-achieving students, however, were more likely to complete two-year and four-year degrees, as were eligible black and Hispanic students. We also find that Knox Achieves is associated with significantly higher in-state earnings up to 7 years after high school, although estimated effects taper thereafter. These medium-term labor market effects are driven by differential retention in in-state work, as well as higher earnings conditional on working.

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I. Introduction

The history of higher education is threaded with private and public efforts to make the endeavor "free" of tuition for needy students, students studying for particular vocations, returning veterans, and students enrolling in new and growing institutions. Individual need-based scholarships date back to the 12th century when students at the University of Bologna (originally but temporarily a free institution) pooled resources to help countrymen repay their debts (Fuller, 2014). The tradition of private altruistic scholarships arrived in America when Harvard University established the colonies' first endowed scholarship for poor students in the late 17th century (Wilkinson, 2005). Today, many nations go well beyond need-based aid: free or nearly free postsecondary education is a defining feature of university systems in Scandinavia, Brazil, Mexico, and elsewhere.

While the ethos of need-based aid has a long precedence in the United States, the idea that education should be free for *any* student was rarely institutionalized beyond secondary grades.[2] Until recently, the most sweeping example of public support for free higher education was contained in California's 1960 Master Plan for Higher Education, which stipulated that state residents pay no tuition. Escalating enrollment fees have since eroded the Master Plan's intent.

Although national or statewide free higher education has remained infeasible for most of the U.S. timeline, private philanthropists found a way to provide college tuition as an entitlement to traditional-aged students residing in particular cities. The beginning of the modern movement for free higher education is often attributed to the Kalamazoo Promise of 2005, which committed to pay the college tuition of Kalamazoo high school graduates in the classes of 2006 and later who enrolled in one of Michigan's public colleges or universities.[3] Kalamazoo Promise was

[2] Scattered individual exceptions include military academies, Berea College, the Free Academy in New York City (today's tuition-collecting City University of New York), the Williamstown Free School of 1791 (now Williams College, which charged tuition starting in 1793), and Cooper Union in New York City (which began charging tuition in 2014).

[3] Kalamazoo Promise was one of the more prominent modern scholarships with "place-based" eligibility criteria, but it was not the only one. Earlier examples of place-based grants include the Clemens Foundation program of Philomath, Oregon, which originated in 1959 to benefit the small logging town's high school graduates; the 1990 Philadelphia Education Fund, Online to College, a 1998 last-dollar scholarship for California's Chaffey College students who graduated from the Ontario-Montclair school district east of Los Angeles; and the Ayres Foundation Scholars Program, a last-dollar scholarship started in 1999 for students in three rural Tennessee counties. Another early program is the Oklahoma Promise, which started in 1991. It targets low-income students, with a maximum family income of $50,000 per year. See Mendoza and Mendes (2012) for an analysis of college persistence in the wake of the Oklahoma Promise.

envisioned in equal parts as a community revitalization tool and financial aid package for the erstwhile manufacturing hub's needy and middle-income students (Zipp, 2005). Between 2005 and 2016, place-based scholarships proliferated across the country. Many, like Kalamazoo Promise, were intended to retain residents and students in shrinking city schools. Most were privately, and generously, funded.

In 2014, Tennessee passed the first state legislation since California's Master Plan devoting public resources toward making college free for all state residents. At the time it was implemented, Tennessee Promise fit into the state's "Drive to 55" campaign to increase postsecondary attainment among the working-age population from 39.3%[4] to 55% by the year 2025. Unlike the California plan of the late 1960s, Tennessee Promise covered tuition and required fees, but only for high school graduates making a seamless transition to public two-year postsecondary institutions in the state. As a "last-dollar" scholarship, Tennessee Promise pays for the gap between the value of two-year tuition plus fees and a student's entitled grants and scholarships from federal, state, and institutional sources. The program's first beneficiaries—numbering over 16,000 according to state figures—enrolled in college in the fall of 2015, contributing to a 10% year-over-year rise in first-time freshmen enrollment. Tennessee Promise was followed by several similar initiatives in other states. To date, there are 15 active and 18 proposed statewide promises of free college, most of which are structured as last-dollar aid (Jones and Berger, 2018).

Tennessee Promise was closely modeled after a privately funded last-dollar program in Knox County, Tennessee, known as "Knox Achieves" from 2008-2011, and then "tnAchieves" from 2011 thereon.[5] Rather than city revitalization or the ethos of free higher education *per se*, Knox Achieves, tnAchieves, and Tennessee Promise were motivated by workforce development, the idea that higher education was necessary for individual and state prosperity, and evidence pointing to a skills gap between employer needs and the state's human capital (Carnevale and Smith, 2012).

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[4] https://www.luminafoundation.org/stronger_nation2016

[5] tnAchieves and the Ayres Foundation Scholars Program remain in operation as Tennessee Promise partnering organizations that coordinate mentoring, community service, and other student supports. tnAchieves serves 90 counties across the state, and the Ayres Foundation serves five.

It is too early to assess whether Tennessee Promise will have the intended effect of increasing postsecondary attainment for traditional college students, although enrollment gains give cause for optimism. But the effect of Knox Achieves availability on college persistence and completion may foreshadow the effect of current and proposed statewide programs like the Tennessee Promise. Knox Achieves raised college enrollment among eligible high school graduates by about 3 percentage points, or 5-6% of average matriculation rates in the Knoxville and East Tennessee area (Carruthers and Fox, 2016).

By assessing the effect of Knox Achieves availability and participation on college completion, we provide the first insights on how a last-dollar scholarship program shapes student attainment and earnings. Our fundamental empirical challenge is characterizing the counterfactual without the benefit of plausibly random variation in eligibility. Like many place-based programs, eligibility for Knox Achieves was transparent and unbounded by income or merit criteria. Every Knox County 12th grader beginning with the class of 2009 was eligible, and students participated from every high school in the county. Universal eligibility was a critical feature of the program, which sought to simplify the question of college price with a powerful message of "free" community college for any interested student. We take advantage of geographic and intertemporal variability in access to Knox Achieves to estimate the effect of the program on college and labor outcomes, relying on difference-in-difference and matching identification alongside a host of robustness and falsification tests.

Relative to the best available counterfactual, Knox Achieves eligibility is associated with a higher likelihood of attaining a two-year postsecondary credential, a negative but imprecisely estimated change in the likelihood of attaining a four-year college degree within 6 years of high school, and higher earnings 7 years after high school, tapering in years 8-9. These helicopter-level intent-to-treat effects mask heterogeneity with important policy implications. Moderately low-income and lower-achieving students appear to have benefitted most from access to free community college, exhibiting significant increases in all levels of attainment. For these students, the last-dollar scholarship may have met financial needs not covered by family resources available to higher-income students, need-based aid available to lower-income students, or merit-based aid available to higher-achieving students.

Democratization of two-year college access comes at some cost, however, as eligible students were no more or less likely to complete a bachelor's degree within 6 years, and the lowest-income students actually saw significant declines in four-year college completion rates. Students who started in a community college rather than a four-year school because of Knox Achieves would have had to navigate a transfer pathway to attain a bachelor's degree, which can be a complicated, opaque process (Boatman and Soliz, 2018), and they may have been further dissuaded by steep changes in out-of-pocket tuition between the two sectors. As a result, our back-of-the-envelope calculations suggest that the net benefits of participating in a program like Knox Achieves, as measured by expected changes in lifetime earnings, are uncertain and will depend critically on the extent of substitution between community colleges and four-year degrees, as well as future returns to those degrees.

In terms of short-term earnings, Knox Achieves eligibility appears to significantly raise in-state earnings covered by Unemployment Insurance (UI) 4-7 years after high school, tapering in the 8th and 9th years. We delve into two potential mechanisms pushing earnings up: participation in UI-covered work, and industry of employment. We find that Knox Achieves eligibility and participation are associated with a sustained higher likelihood of any employment in UI-covered jobs 1-9 years after high school, as well as lower rates of attrition. Program participants tend to work in more lucrative industries (i.e., industries with higher U.S. average earnings) than other students, and this tendency grows over time, but it may reflect positive selection rather than a causal effect of free community college. Countywide, the introduction of Knox Achieves did not significantly change our summary measure of industry quality.

Except where noted otherwise, results are robust to a large and flexible set of observable student features, school features, and interactions therein, and we estimate that non-zero treatment effects are robust to a substantial degree of selection on unobservables. Estimated effects of Knox Achieves eligibility on two-year attainment and earnings are large and atypical among random placebo permutations, whereas findings for college credits within four years and bachelor's degree completion within six are less distinguishable from permutation noise. Preferred specifications are well balanced and we do not detect consistently significant OLS "effects" on pseudo-outcomes estimated from pre-program predictions. Matching treatment effects tend to be no smaller than linear difference-in-difference estimates.

Nearly all of the previous work on Promise programs focuses on generous first-dollar scholarships funded by private sources and targeting students in particular cities. Last-dollar scholarships are more financially viable for statewide efforts, however, because they can make similar promises of free college but contain costs by counting other grants and scholarships against potential benefits and limiting those benefits to less costly postsecondary options. As our results suggest, this subsidized but constrained set of choices can benefit students in the middle of the income distribution and the bottom half of the achievement distribution, who might not have the family resources, need-based aid opportunities, or merit-based aid opportunities of others. Policymakers need to be aware of this large but often-overlooked group of potential college students, whose enrollment and completion may determine the degree to which the college-educated population will expand in the future. Estimated effects are larger for black and Hispanic students as well, who have been traditionally underrepresented among college completers. At the same time, evident substitution from four-year schools to two-year community colleges, and lower bachelor's degree completion among higher-achieving and lower-income students, highlights a potential consequence of restricted, last-dollar scholarship programs as well as the costs and hurdles that students face when they consider transferring from two-year to four-year schools.

II. Policy Background and Related Research

Knox Achieves launched with the 2008-2009 class of Knox County 12th graders after a group of local business and civic leaders contributed funds to cover community college tuition and fees for up to 500 students. Any public high school senior in the county was eligible to apply. The 500-student ceiling was nonbinding for the class of 2009 (493 signed up and 241 later enrolled) and eliminated for later, larger cohorts. Interested students signed up for Knox Achieves in the fall of their senior year of high school. This necessary first step—signing up for more information and support leading to free community college—will serve as one measure of the Knox Achieves treatment in analyses to follow. A broader and preferred treatment indicator covers all students who had access to Knox Achieves, i.e., all high school seniors in the graduating classes of 2009-2011.

In order to retain eligibility, participants from the fall signup lists were expected to meet with mentors (volunteers drawn from the community), file a Free Application for Federal

Student Aid (FAFSA) in the spring of their senior year, graduate from high school, verify their FAFSA if necessary, complete an eight-hour community service project, and then seamlessly enroll in a community college. In return, Knox Achieves paid for tuition and mandatory fees for up to five semesters. Between the fall of senior year and the fall of the following year, program attrition measured 45 percent; that is, 55 percent of fall signees fulfilled program requirements and enrolled in a community college the following year, while others enrolled in a different sector, did not enroll in college, or enrolled in a community college without Knox Achieves.

By studying Knox Achieves, we contribute to a small but growing literature on location-based "promise" programs. A common theme of these programs is that a locality makes a promise to provide postsecondary funding, often in conjunction with other services, for students who meet noncompetitive eligibility requirements in addition to living and attending secondary school in the location. There are over 140 local place-based programs that meet this broad definition,[6] in addition to at least 15 active and 16 proposed statewide programs (Jones and Berger, 2018). Promise programs exhibit many differences regarding the amount of aid, student GPA and residency requirements, and the type and number of institutions covered. Some, like the El Dorado Promise, commit to cover costs at any accredited college or university in the country. Others, such as the Kalamazoo Promise, limit benefits to institutions within a state. And still others, such as the Chaffey College Online to College initiative, are limited to one institution. Swanson et al. (2016) survey the landscape of Promise initiatives in the U.S. as well as the limited research base seeking to assess the impact of Promise aid on student outcomes.

Exposure to a place-based scholarship opportunity has been shown to increase the likelihood of college enrollment in several settings across the U.S. (Carruthers and Fox, 2016; Daugherty et al., 2016; Bartik et al., 2019; Page et al., 2018). Regarding college completion, Bartik et al (2019) find the Kalamazoo Promise raised the likelihood of completing a bachelor's degree by 25 percent, and Swanson and Ritter (2018) find that the El Dorado Promise led to 32 percent gain in bachelor's degrees. Those two applications each focus on a generous and privately funded "first dollar" free college initiative that pays for a student's college tuition irrespective of need-based and merit-based aid from other sources, and irrespective of whether a student enrolls in a community college or a more costly four-year university. Last-dollar

[6] See the Upjohn Institute *Promise Database* here: https://www.upjohn.org/promise/.

programs like Knox Achieves and Tennessee Promise cover any gap between college tuition and financial aid from institutions, states, and the federal government, and further contain costs by restricting benefits to community college students. Knox Achieves requires that applicants fill out a FAFSA, and any federal or state aid received by the student as a result of FAFSA processing reduces the amount of aid provided by the program. Eligible students still receive tuition-free community college, but the cost of the program is then shared with other sources. As a result, program costs for Knox Achieves were just under $1,000 per enrolled student per year, versus up to $10,000 per student-year in the New Haven and Pittsburgh Promise programs, $8,000 per student-year in Kalamazoo, and up to $9,000 in El Dorado. Students in a first-dollar program, but not in a last-dollar program such as Knox Achieves, can use scholarship funds in excess of tuition to offset expenditures for books, supplies, transportation, and living expenses.

We add to what we know about college financial aid in general, and promises of free college in particular, in a few ways. Foremost, we examine the effect of Promise availability on longer-term credit accumulation and college completion; the Bartik et al. (2019) study of the first-dollar Kalamazoo Promise and Swanson and Ritter (2018) study of the first-dollar El Dorado Promise are the only others we are aware of to do so quasi-experimentally. We analyze students' college persistence and completion over a time period of at least six years following high school.

Second, we provide the first estimates of college completion for a last-dollar scholarship program that only covers community colleges, extending results reported by Carruthers and Fox (2016) for college enrollment. Knox Achieves is a lower-cost, lower-benefit aid vehicle with a broader base of eligible students, compared with most first-dollar city programs, such as Kalamazoo and El Dorado, that entail high school GPA requirements and/or residency for several years. Knox Achieves was available to every high school senior regardless of GPA or tenure in the county, but the program provides scholarships only for community colleges. About half of enrolled participants qualify for enough Pell aid that they receive no funding from Knox Achieves itself, which is also true for the program's successor, statewide Tennessee Promise. Our findings are particularly useful for policymakers considering publicly-funded, last-dollar programs where first-dollar programs are prohibitively expensive.

Third, we characterize the effect of free community college on employment, earnings, and industries of occupation up to 9 years after high school, quantifying the medium-term tradeoff between democratization of college access and, for some students, diversion from what is traditionally a higher-return path through four-year college.

And finally, a necessary methodological difference from the most related literature is how we characterize the counterfactual to Knox Achieves access. Universal place-based eligibility is a core feature of the program, and one that is certainly worth study, but it does not permit the kind of difference-in-difference identification used to evaluate programs where benefits are conditioned on GPA or how long a student lived in the qualifying city. Rather, the first conditions of Knox Achieves are (1) attending a Knox County high school as a senior in the class of 2009, 2010, or 2011, and (2) signing up for the program in the fall of senior year. We use these initial points of access as sources of identifying variation in the Knox Achieves treatment. Recognizing that both plausibly coincide with other determinants of college success, we scrutinize *ex ante* expectations for participating students, we explore the extent to which linear regression results are sensitive to much more flexible functional forms alongside data-driven model selection (Hansen et al., 2014), and we gauge the potential severity of selection on unobservables using coefficient stability methods proposed by Oster (2017). We also relax linearity assumptions by pursuing complementary matching techniques. Matching identification rests on a similar unconfoundedness assumption as linear difference-in-differences, but it relaxes functional form assumptions and minimizes the influence of outliers. This is particularly valuable when covariate distributions are distinct across treatment and control units (Imbens, 2015), which is certainly the case with Knox Achieves participants and other students. A remarkably consistent story echoes across these different approaches, where free community college leads to large gains in two-year college completion, at best no change in four-year college completion, and better work outcomes several years after high school.

III. Methods

III.A. Data and Summary Statistics

We begin with longitudinal administrative data describing the universe of 2006-2007 through 2010-2011 high school seniors in Tennessee's public school systems, linked to their

enrollment records in public two-year and four-year higher education institutions throughout the state and in-state earnings covered by Unemployment Insurance. We join these data with Knox Achieves participant lists from the senior classes of 2009-2011. Participant lists include all students who signaled their interest in the program in the fall of 2008-2010, by signing up to receive more information and a volunteer mentor. In some analyses to follow, these lists compose the Knox Achieves treatment group, even though just 55 percent of fall participants later enrolled in a community college as a Knox Achieves student. Additionally, we observe initial college enrollment details from the National Student Clearinghouse. Clearinghouse data on hand do not extend beyond the year immediately following high school. Accordingly, our focus is on postsecondary outcomes in Tennessee's public colleges and universities. The Tennessee Higher Education Commission (THEC), a coordinating body spanning the state's university and college systems, maintains data on these students. Ninety-one percent of college-going students in the state enroll in a THEC institution, and results to follow account for the plausible idea that Knox Achieves swayed some higher achieving students to enroll in a public institution rather than a private or out-of-state institution (details are provided in Section III.B).

Table 1 provides descriptive statistics for all Tennessee 12th graders (Column 1), Knox County Knox Achieves signees (Column 2), and Knox County non-participants (Column 3), omitting high school graduates who enrolled seamlessly in a non-THEC higher education institution. Knox Achieves participants accounted for 16.8% of eligible cohorts. As plainly seen from the table, participants were substantially more likely to enroll in college (two or four year) than their peers in Knox County and throughout Tennessee. Just under half of Knox County non-participants seamlessly enrolled in college, versus 75 percent of program participants.

Outcomes of interest include THEC accumulated credits within two and four years of high school, any enrollment in a four-year institution, postsecondary certificate or associate's degree attainment within four years of high school, bachelor's degree attainment within six years, and labor market outcomes up to nine years after high school. Labor market outcomes are derived from in-state earnings recorded in the state's Unemployment Insurance system, which covers the vast amount of earnings from work among state residents, with notable exceptions of earnings from self-employment, some agricultural or federal employers (including the military), and any earnings from working in other states. Age-earnings profiles vary across industries,

which complicates the comparison of early-career earnings. To address this, we compute earnings by fiscal year (third quarter of each calendar year through second quarter of the next calendar year) in the nine years following high school as well as an industry score, which we construct from a worker's industry (specifically, its 4-digit NAICS code) and U.S. average earnings among workers covered by Unemployment Insurance. U.S. figures are drawn from the Census Quarterly Workforce Indicator. For each year where a worker has in-state, UI-covered earnings, we compute their industry score as the average annual U.S. earnings in that industry that year, or as a weighted average if they worked in multiple industries. UI-covered earnings and industry scores are inflation-adjusted to 2019 dollars using the Consumer Price Index for Urban Consumers.[7]

Knox Achieves participants outperformed other students in terms of two-year postsecondary credentials. Knox Achieves students are 3-6 times more likely than their peers to attain a certificate or associate's degree within four years, at least 200% of the "normal time" to complete those credentials. Relative to the state and non-participating peers, however, Knox Achieves participants are less likely to graduate with a four-year college degree. We find that 17 percent of participants receive a bachelor's degree within six years of completing high school, noticeably below the rate of 19 percent for all 12th graders and 25 percent for non-participants in Knox County. Earnings in the year immediate after high school are similar across groups, measuring $4,470-5,440 on average, which includes missing earnings recorded as zero.[8] We observe earnings up to seven years after high school for all 2006-7 through 2010-11 seniors, up to eight years after high school for the first four cohorts, and up to seven years after high school for the first three. Results in tables to follow focus on the estimated effects of Knox Achieves on earnings seven years later, which we can quantify for all three Knox Achieves cohorts, although Figures 2-3 trace effect estimates for all observed years.

Looking to student characteristics, the profile of a typical Knox Achieves student is one who is socioeconomically disadvantaged but performing close to or better than par in terms of standardized achievement. Program participants are more likely to be female, non-white, and

[7] https://fred.stlouisfed.org/series/CPIAUCSL
[8] Results to follow include analyses of log-earnings among those with non-missing earnings as well as the binary incidence of having any UI-covered earnings in a given fiscal year.

lower-income than their peers throughout the county or state, but they have similar or better composite scores on end-of-course exams and the ACT.

III.B. Linear Estimation

To begin assessing the potential impact of Knox Achieves availability on students' college success, we estimate the following student-level model for the 12th grade classes of 2007-2011, which includes all eligible Knox County seniors from 2009-2011 as well as ineligible students from other counties and pre-program cohorts:

$$Y_i = \alpha_0 + \alpha_t + \alpha_s + KA_i\gamma + X_{ist}\beta + \varepsilon_{ist}, \quad (1)$$

where Y_i is a college outcome such as credits earned or associate degree received for student i, KA_i is either an indicator for Knox Achieves availability (equal to one for all Knox County seniors in the classes of 2009-2011) or an indicator for seniors who signed up for Knox Achieves in the fall, α_t is a cohort fixed effect, α_s is a school fixed effect, and X_{ist} is a vector of observable features describing student i and his or her school s. Students with no record of college enrollment have Y_i coded as zero. Robust standard errors allow for ε_{ist} residuals to be correlated within counties. Student controls include continuous or binary variables describing gender, race, Hispanic ethnicity, repeating the 12th grade, free or reduced-price lunch eligibility at any time since 8th grade, earnings during junior and senior year, the number of districts and counties attended between 8th and 12th grades, ACT composite and subject scores, standardized end-of-course exam scores (English, math, science), the number of end-of-course records overall, and indicators for missing data on these variables.[9] These features are intended to characterize students' basic demographics, ability, and need, each of which is expected to be important signals or determinants of college success. School controls include the student-teacher ratio, and the share of students who are white, Hispanic, or eligible for free or reduced-price lunch. We also control for schools' urbanicity (indicators for city or suburban locales), schoolwide Title I status (another signal of economic disadvantage), and contemporaneous county unemployment rates.

[9] Missing ACT and end-of-course scores are imputed at the 25th percentile.

One threat to interpreting γ estimates as the causal effect of Knox Achieves is the possibility that the sample of students with observable college credits and degrees is itself influenced by Knox Achieves. Although we can identify the immediate college destinations of almost all 2007-11 high school graduates through the National Student Clearinghouse, we only observe credit accumulation and completion for students who enroll in Tennessee's public universities and colleges. And since Knox Achieves emphasized community college enrollment, it is plausible that our capacity to observe a student's postsecondary progression was influenced by the program itself. Indeed, using the Equation (1) model, we find that Knox Achieves participation reduced the likelihood of enrolling in a private or out-of-state institution by 5 percentage points, nearly equal to the 5.6% share of all ineligible students who enroll as such. Estimates of γ would overstate the effect of Knox Achieves on success in college if students who decided to enroll in a public in-state institution because of Knox Achieves were innately higher-achieving, i.e., positively selected, relative to their peers. To account for this possibility, main results are reported for a truncated sample, where we exclude a portion of Knox Achieves participants with the largest college credit accumulation after four years, under the assumption that participants who were convinced to enroll in one of Tennessee's public colleges or universities would have persisted in college longer than all other program participants. How much longer is not clear because we cannot observe accumulated credits in the National Student Clearinghouse records on hand. Main results are reported with the top 5% of participants excluded.

Another hazard of using Equation (1) to estimate the effect of Knox Achieves engagement on college outcomes is the idea that unobserved factors coincide with program availability or take-up as well as subsequent college outcomes. Differences in the college prospects of Knox County students or participants' inherent interest in a community college education are chief examples of such factors. We respond to this threat in a few ways. First, we look for differences in expected college behavior by Knox Achieves availability or participation. Findings discussed in Section IV indicate that Knox Achieves participants and Knox County students more broadly were on roughly the same trajectory as their respective counterparts who did not engage with the program, and any differences are too small to explain away estimated program effects. Second, we estimate Equation (1) with and without school fixed effects. Controlling for school fixed effects limits identifying variation in Knox Achieves to non-

experimental student interest in the program more so than quasi-experimental program availability. Nevertheless, Equation (1) appears to be more balanced with school fixed effects (see Section IV), and results are broadly similar across specifications with and without school fixed effects. Third, we test whether results from linear estimates are robust to much more flexible specifications of the control vector, adding several hundred non-linear terms and interactions. And finally, we estimate the extent of selection on unobservables, as a proportion of selection on observables represented by X_{ist}, that would imply a true γ of zero for each outcome. We make this inference using Oster's (2017) approach, which compares unconditional and conditional γ estimates along with unconditional and conditional R^2 values, to gauge the threat from selection on unobservables.[10] A high degree of selection on unobservables proportionate to the estimable degree of selection on observables would be necessary to explain away the magnitude of γ in settings where coefficients change very little but explained variance (R^2) grows much larger between unconditional and conditional specifications.

As a two-way fixed effects estimator, under the identifying assumption that successive treated and untreated cohorts would have followed the same conditional trajectory of outcomes ("common trends"), $\hat{\gamma}$ can be expressed as a weighted average of two-by-two difference-in-difference estimates between treated and untreated schools (Chaisemartin & d'Haultfoeuille, 2019). Weights can be negative, and if average treatment effects are heterogeneous, this means that $\hat{\gamma}$ can be biased or even of the opposite sign as average treatment effects. Using the procedure outlined by Chaisemartin et al. (2019), we find that just 4% of weights in our application are negative, with values that sum to 1.6E-05.

The Knox Achieves treatment affected a small number of groups: 18 out of 369 schools statewide. As Conley and Taber (2011) and Ferman and Pinto (2019), among others, have shown, cluster-robust standard errors can over-reject the null when there are a small number of treatment groups. To assess whether our conclusions are vulnerable to this, for each outcome of interest we estimate Equation (1) over 300 permutations, where the KA_i treatment is randomly

[10] This method is an extension of work by Altonji et al. (2005) inferring the necessary degree of selection from coefficient stability. To proceed, we must assume linear functional forms, a proportionate selection relationship, and an upper bound on R^2. Following Oster (2017), we assume that the maximum R^2 is equal to 1.3 times the R^2 observed in the fully conditioned specification of Equation (1).

reassigned to other schools. Results broadly support our main inferences, and are discussed in more detail in Section IV.C.

III.C. Matching Estimation

The statistical profile of Knox Achieves participants summarized in Table 1 suggests that they were notably different than non-participants in terms of demographics, achievement, and financial security. This difference may mean that models such as Equation (1) will depend too heavily on extrapolation when forming estimates of the conditional gap in outcomes between treated and untreated students. In such cases matching estimators can be a suitable alternative to linear models.

The intuition with matching is to pair each Knox Achieves participant with a quantitatively similar non-participant and interpret the average difference in outcomes across matched pairs as the treatment effect. We take two complementary approaches to defining similarity between treated and control students. We first pair participants to similar students in terms of several observable features in X_{ist}: gender, race, Hispanic ethnicity, repeating the 12th grade, free or reduced-price lunch, junior year earnings, number of districts since 8th grade, ACT composite, English and math end-of-course exam scores, the number of end-of-course exams on record, schoolwide percent white, schoolwide percent with a history of free lunch eligibility, and the county unemployment rate. Mahalanobis matching computes a distance metric describing the similarity of this control vector between every *i, j* pair of students and matches treated students to the untreated nearest neighbor in terms of this distance metric. For Mahalanobis treatment effect estimates, we compute standard errors according to Abadie and Imbens (2006). Figure A1 in the appendix depicts the average standardized gap in observable features before and after matching Knox Achieves participants to non-participants enrolled in the same county. As one would hope, matching on these covariates limits observable differences between Knox Achieves participants and comparison students.[11]

Our second matching approach is to pair Knox Achieves participants with non-participants according to their estimated likelihood of participating in the program. We estimate

[11] Mahalanobis matching minimizes the distance metric between matches without regard for which variables in the matching vector are most important for predicting college outcomes. With this in mind, our preferred Mahalanobis matching vector is limited to a subset of key X_{ist} variables.

this propensity by logit for seniors who had the opportunity to participate, i.e., Knox County classes of 2009-2011. Predictive factors include all variables represented in X_{ist}. Parameter estimates are mapped to seniors in other counties and pre-program cohorts. We use a nearest neighbor propensity score estimator where matches are constrained to be within two percentage points (i.e., a caliper of 0.02), within the range of overlap between treated and control propensity (i.e., with common support), and below the top one percent of treated students' propensity distribution. Figure A2 in the appendix plots the distribution of predicted propensity by Knox Achieves participation. While participants generally have a higher propensity than non-participants, the area of common support is inclusive of them all.

IV. Results

IV.A. Balancing Tests

The critical identification assumption allowing γ estimates from Equation (1) to be interpreted as a causal effect of Knox Achieves is that participation or access to the program was conditionally independent of unobserved determinants of college persistence and completion. This assumption would be violated if, for example, Knox County students were following a divergent path relative to the rest of the state, in terms of expected college outcomes, or if unobserved interest in a community college education coincided with expected college persistence and completion. Although these scenarios and others like them are untestable, we can utilize two pre-program cohorts to get a sense of how college outcomes would have changed in Knox County in the absence of Knox Achieves. Specifically, we estimate Equation (1) for the Tennessee classes of 2007 and 2008, substituting a linear time trend for cohort fixed effects. We then map coefficient estimates to the classes of 2009-2011, when Knox Achieves was available to Knox County seniors. Finally, we estimate Equation (1) for fitted outcomes of all students from 2007 to 2011. Standard errors are computed by bootstrap from 200 replications of this last step on random subsamples of 10,000 students. This test is a more parametric version of common identification checks that visualize parallel trends across treatment and control groups. Table 2 lists results for the pseudo-effect of Knox Achieves on college credit accumulation, program completion, and earnings.

In Columns 1 and 3 the measure of Knox Achieves treatment is the broadest measure of eligibility, i.e., an indicator for all Knox County high school seniors in the classes of 2009-2011. The Column 2 and 4 models use a finer measure of treatment: an indicator for students who signed up for Knox Achieves in the fall of their senior year. Columns 1-2 include county fixed effects rather than school fixed effects.

The pattern of results in Column 1 suggests that *ex ante* predictions from an intent-to-treat specification with county fixed effects are fairly unbalanced, in that we would expect Knox Achieves eligibility to be associated with 6.5 additional credits within four years, a 0.6 percentage point lower likelihood of associate degree completion, and a 5.3 percentage point higher likelihood of bachelor's degree completion, based solely on post-treatment observable student features and not necessarily the program itself. In other words, even in the absence of Knox Achieves, there would have been a strong tendency for eligible students to accumulate more college credits and attain four-year college degrees at a higher rate than the counterfactual. Knox Achieves *participants* do not appear to share that tendency (Column 2), although their (imprecise) expected gains in college credits and earnings after college are large.

Once we control for fixed but unobserved properties of treated schools (as seen in Columns 3-4), we find just one statistically significant difference in expected outcomes across treated and comparison students. Based on observable characteristics and school fixed effects, Knox County students in the classes of 2009-11 were *ex ante* 0.3 percentage points more likely to attain a postsecondary certificate than students in other counties (Column 3). As we show below, however, actual treatment effect estimates for that outcome are many times greater than 0.3 percentage points. Conditional expectations for Knox Achieves participants were not significantly different than for non-participants throughout the county and state (Column 4), although as in the Column 2 specification, participants were expected to exhibit large gains in earnings based on observable characteristics alone, with or without Knox Achieves.

Going forward, our preferred specification of Equation (1) controls for school fixed effects and estimates either the intent-to-treat effect of eligibility, where KA_i is an indicator for Knox County seniors in the classes of 2009-11, or the treatment-on-the-treated effect of participation, where KA_i is an indicator for students who signed up to receive mentoring and more information about the program.

IV.B. Equation (1) results

Table 3 lists linear estimates of γ for two different specifications of Equation (1), where we include the full sample of students from 2007 to 2011. For each outcome and each specification, coefficients are listed first, with robust standard errors in parentheses, and control means below standard errors. Column 1 reports results where KA_i is specified as a broad eligibility indicator, meaning that γ estimates in Column 1 can be interpreted as intent-to-treat estimates. We find that Knox Achieves availability preceded a countywide 1.6-credit, or 9%, rise in college credits two years after high school, along with a 1-3 point rise in postsecondary certificate or associate's degree attainment within four years, and a statistically insignificant 0.5-percentage point fall in bachelor's degree attainment within six years of high school. Estimated effects on certificate completion are quite large, exceeding the certificate attainment rate for ineligible cohorts, and estimates for effects on associate degree completion are 25% of the control mean. The imprecise coefficient estimate for bachelor's degree attainment reported in Column 1 suggests that eligibility was associated with a fall in bachelor's completion as large as 1.4 percentage points (7%), or a gain no larger than 0.3 percentage points (2%). Turning to earnings after high school, the Column 1 specification finds a $732.70 conditional increase in annual earnings for eligible cohorts, or 5% of the control mean.

Column 2 reports conditional differences in college outcomes between program participants and non-participants for the model with school fixed effects. As noted in Section III.B, school fixed effects sacrifice cross-county identifying variation in Knox Achieves availability for a more flexible representation of unobserved school-wide heterogeneity in factors that determine college enrollment, persistence, and completion. The model suggests that Knox Achieves participation preceded a 2.5 typical credit gain over non-participants after two years (14% of the control mean), a small and weakly significant decline in accumulated credits after four years, and significantly more presence and success in two-year college institutions than in four-year institutions. Estimated gains in two-year degree and certificate attainment of eight and nine percentage points, respectively, well exceed typical attainment rates for those credentials. Participants also exhibit 7-percentage-point reductions in the likelihood of four-year degree receipt, and they earned $1,456.49 more than their peers seven years after high school.

If countywide trends in postsecondary outcomes were driven entirely by Knox Achieves, and if spillover effects were minimal between participants and non-participants, we would expect Column 2 estimates to be about six times as large as those in Column 1, based on 16.8% participation among eligible cohorts. For earnings, treatment effects implied by Column 1 are much larger than what we observe among participants: over $4,000 in additional earnings per year, of which observed Knox Achieves participation can explain just one-third. By contrast, intent-to-treat effects for associate and bachelor's degree completion imply notably smaller treatment effects than what we estimate for those outcomes: associate gains of 6 percentage points rather than 9, and lower bachelor's attainment by 3 percentage points rather than 7. We can reconcile these differences with two plausible varieties of unobserved factors that co-moved with Knox Achieves eligibility or participation. First, it is reasonable to think that something other than the program affected postsecondary interests and later employment opportunities among Knox County students beginning with the class of 2009; locally favorable growth following the Great Recession, perhaps (Murray, 2013). Second, it is even more reasonable to think that students who signaled their interest in free community college were more inclined toward associate programs than college and university programs in ways that were unrelated to other observable controls. In Section IV.C we show that inclination would have to be many times more influential on attainment than observable characteristics, but nevertheless, for much of this section we prioritize inferences from intent-to-treat estimates. The effect of universal free community college *availability*, versus take-up, is more relevant for policy, and more plausibly independent of unobserved factors.

Figure 1 illustrates the relationship between Knox Achieves and γ estimates on earnings for 1-9 years following high school. Specifically, left-hand Panels I, III, and V contain the regression coefficients for Knox Achieves eligibility, and right-hand Panels II, IV, and VI trace results for participation. We see a positive association between Knox Achieves eligibility and earnings starting 5 years after high school but tapering by 8-9 years after high school. The highest benefit is $732.70 in additional earnings the 7th year after high school (also reported in Table 3), representing 5% of mean annual earnings among ineligible students. The increase in earnings for Knox Achieves participants is more than twice as large as for eligible students, and exhibited a similar taper 8-9 years after high school.

The earnings outcomes depicted in Panels I-II of Figure 1 are inclusive of unobserved earnings, where we assign a value of zero. This is an informative summary measure of potential effects on in-state earnings, but one that combines extensive and intensive margins of work. And typical of earnings more broadly, the distribution of dollar values is right skewed. The second two rows of Figure 1 depict estimated effects on the binary incidence of having any in-state UI-covered earnings (Panels III-IV) and log earnings among those with any earnings (Panels V-VI). Results indicate that Knox Achieves eligibility and participation are both associated with a higher likelihood of working in Tennessee's UI-covered occupations 1-9 years after high school, as well as higher log earnings among UI-covered workers 1-8 years after high school.

Knox Achieves is linked to a lower likelihood of attrition from UI-covered work, not just temporally as in Figure 1 Panels III-IV, but in a more lasting sense as we show in Figure 2 Panels I-II. Following Grogger (2012), we define attrition from the earnings sample as the beginning of a terminal run of zero or missing earnings. We then apply Equation (1) to the incidence of attrition 1-6 years following high school. Regardless of whether Knox Achieves is measured in terms of eligibility (Panel I) or individual-level participation (Panel II), the effect is similar: Knox Achieves is associated with a reduction of attrition of at least 2 percentage points. However, the drop attrition is noticeably more pronounced when measuring individual-level participation in Knox Achieves. Higher earnings shown in Figure 1 are in part a function of a significantly higher likelihood of observing Knox County graduates and Knox Achieves participation over time. It is not yet clear, however, if affected students are more likely to work at all, or if they are less likely to leave the sample of Tennessee UI-covered workers for other opportunities. In Equation (1) subgroup results not shown, we find that Knox Achieves is associated with differentially *less* attrition among lower-achieving students, and *more* attrition among low-income, higher-achieving students. This is consistent with negative selection into observed earnings, which would tend to bias results for earnings inclusive of zero downward.

Recognizing that earnings in the decade after high school might not be indicative of long-term returns, we estimate Equation (1) for each worker's industrial score, equal to average US earnings in their industry. Intent-to-treat effects depicted in Panel III of Figure 2 are small and close to zero; when combined with results for other outcomes, this implies that eligibility is linked to more work but not necessarily more lucrative industries. Knox Achieves participants,

however, exhibit higher industrial scores immediately after high school, and the gap grows to over $3,000 by the 9th year after high school.

As shown in our earlier work, the message underlying free community college policies is evidently a compelling factor that can sway students on the fence about going to college at all, but it can also reroute students to begin their postsecondary education in a two-year college rather than a four-year college (Carruthers and Fox, 2016). We found that while much of the effect of Knox Achieves was to push extramarginal students into college, there was a discernible negative effect on the likelihood of starting in a four-year college, and this substitution was more pronounced for higher-income and higher-achieving students. Shifting preferences for where to start college, combined with ambiguous findings for eventual bachelor's degree receipt, speaks to the long-term return to last-dollar programs like Knox Achieves because the earnings premium that students receive from a bachelor's degree is high relative to the return from community college completion. From a social perspective, higher earnings from more college completers will not necessarily offset losses from fewer four-year completers. In Section IV.D we explore this tradeoff more formally, relying on estimates of lifecycle returns to education rather than relatively short-run gains in UI-covered earnings.

Focusing on the intent-to-treat specification of Equation (1), where KA_i is an indicator for Knox Achieves availability, Table 4 partitions the Tennessee sample of 2007-2011 seniors into three groups: those who did not participate in the free school lunch program between 8th and 12th grades (Column 1), those who were eligible for free lunch for 1 or 2 years in that time (Column 2), and those who were eligible for at least 3 years (Column 3). Moving left to right, family income likely falls and subsamples are successively more disadvantaged (Michelmore and Dynarski, 2017). For ease of discussion, we label these three groups higher income, middle income, and lower income. Notably, more disadvantaged students in last-dollar Promise programs such as Knox Achieves tend to qualify for federal Pell grants at or exceeding community college tuition. Any discernible treatment effect among these subpopulations may be more attributable to non-financial aspects of Knox Achieves such as mentoring and the upfront message about the cost of college for program participants.

The availability of Knox Achieves is associated with the most improvement in postsecondary attainment for middle-income students (Column 2), compared with higher income

(Column 1) or lower-income (Column 3) students. For example, the increase in accumulated credits is 4.2 (22%) for the middle income group, versus 1.9 (8%) and 1.5 (15%) for higher and lower-income students, respectively. Similarly, the middle income group is the only one where Knox Achieves is associated with an increase in the likelihood of completing a bachelor's degree, at 1.8 percentage points. Both the higher-income and middle-income groups have sizable increases of roughly three percentage points for certificates, compared with an increase for lower-income students of only 1.1 percentage. The lower-income group is associated with a decrease in likelihood of receiving an associate's degrees, in contrast to an increase of 1.3-1.4 percentage points for the other two income groups.

Why might higher-income students be as affected as needier peers, if not more affected, by Knox Achieves support? The program was founded with the intent of helping disadvantaged and first-generation college students, but its universal message and benefits do not exclude students with higher baseline rates of college success. Students without subsidized lunch are not necessarily affluent but will have less support from federal Pell grants. As such, they would receive more in last-dollar aid from Knox Achieves, which could amplify the program's intended effects on 2-year college completion as well as its unintended effects on 4-year college completion.

Table 5 summarizes results of Equation (1) by subgroups according to measures of college readiness: expected persistence in college (Columns 1 and 3), which was estimated using the same pre-program mapping as in the Table 2 balance tests, and average standardized end-of-course achievement prior to high school exit (Columns 2 and 4). Columns 1-2 report results for students above the median of each measure, and Columns 3-4 report results for students below the median. Although results vary greatly across the columns, a general pattern is that estimated effects on two-year college completion are larger in absolute and relative terms for higher-achieving students, whereas four-year completion and 7th-year labor market gains are largest for lower-achieving students. One inference is that higher-achieving students responded to tangible last-dollar financial support in ways that led to more completion in targeted schools, but their initial matriculation shift toward two-year schools set them on a path that led to certificates and associate's degrees at the (imprecisely estimated) expense of bachelor's degrees. For lower-achieving students, the decision of whether to go to college at all may have been more relevant

than the choice between starting in a community college versus a four-year school, and Columns 3-4 of Table 5 are consistent with the idea that the program's effects on initial enrollment translated to higher completion rates several years later. A 1-percentage-point effect on bachelor's degree attainment for lower-achieving students is a meaningful increase over 7% baseline rates for this group (versus 31-32% for higher-achieving students).

Table 6 reports results for Equation (1) estimates by race, Hispanic ethnicity, and gender. We show that that estimated effects on college credit accumulation and completion are larger for black and Hispanic students, both in absolute terms and relative to sample averages. As seen from control means below standard errors, bachelor's attainment rates are typically 8-10 percentage points lower than white completion rates (11-13% versus 21%) for ineligible cohorts in other counties, or in Knox County prior to the introduction of Knox Achieves. Intent-to-treat estimates of 1.3 and 3.0 percentage points for black and Hispanic students, respectively, would narrow that gap by 12-23%. College persistence and completion results are similar for men and women (Columns 4-5), although estimated effects on earnings 7 years after high school are entirely driven by men.

IV.C. Equation (1) robustness

Knox Achieves affected a small number of groups—18 schools and 1 county—and in an intent-to-treat specification like Equation (1) when KA_i is a binary indicator for 2009-11 Knox seniors, this circumstance can result in standard errors that are too small, leading us to over-reject the null and infer significant treatment effects where there might be none. Cluster-robust standard errors such as the ones reported in Tables 3-6 are derived from variance estimators that sum the pre/post residual difference from treated schools with the pre/post residual difference from comparison schools, and by construction the former is very small with few treated groups (Cameron & Taber, 2011; Ferman & Pinto, 2019).

In order to get a different perspective on the precision of our main intent-to-treat findings, we re-estimate Equation (1) over 300 permutations where 18 schools from across the state are randomly selected to be treated by a Knox Achieves placebo. Figure 3 plots the distribution of placebo treatment effects for six outcomes, marking the Table 3 Column 1 point estimate for each with a dashed vertical line. The percent of placebo treatment effects that are larger than the

corresponding Table 3 estimate in absolute value is listed in parentheses for each panel. As expected, these shares are larger than *p*-values implied by Table 3 standard errors, and treatment effect estimates that were imprecisely estimated in Equation (1) with cluster-robust standard errors—credits accumulated within four years and bachelor's degree attainment, are likewise somewhat central in the distribution of placebo effects. Treatment effect estimates for credits within two years, certificate or associate attainment, and earnings 7 years after high school are atypical relative to placebos, however, indicating that our inferences about those outcomes thus far are robust in spite of the tendency for estimates to stand out from the conditional mean when a small number of groups are treated.

Permutations reported in Figure 3 do not account for heteroskedasticity with respect to school size, i.e., the idea that random permutations would discount the importance of treatment effects among larger groups, whose outcomes are less susceptible to noise and short-term deviations than smaller groups (Ferman & Pinto, 2019). As one of the larger metro areas in the state, Knox County high schools' senior cohorts tend to be larger than the untreated average, and so we expect that adjusting for heteroskedasticity would make attainment and earnings results in Figure 3 stand out even more.

Looking to the other specification of Equation (1) reported in Table 3, where KA_i is an indicator flagging students who signed up to learn more about Knox Achieves, treatment-on-the-treated effect estimates rely on a strong assumption that signup was conditionally independent of influential and unobserved factors, such as inherent interest in associate programs or jobs that are well-aligned with such programs. To make these inferences with confidence, we rely heavily on the X_{ist} vector of observable students and school features to control for factors that may influence students' interest in a free community college program as well as their later success in college. Table 7 scrutinizes observable controls more closely and explores the extent to which non-zero treatment effects are robust to more flexible specifications and/or a proportionate degree of selection on unobservables. Here, the focus is on individual-level participation in Knox Achieves.

Column 1 of Table 7 lists Equation (1) results when the X_{ist} vector is limited to cohort fixed effects. This is a nearly unconditional estimate of relative college credit and accumulation gaps between Knox Achieves participants and other students. Knox Achieves participants were

academically similar to their non-participating peers in Knox County but socioeconomically more disadvantaged (Table 1). Nevertheless, Table 7 shows that they accumulated 2-4 more college credits than their cohorts at large, they were 10 percentage points more likely to attain a two-year credential, they were 5 percentage points less likely to receive a bachelor's degree, and they were earning $1,699 more than their peers 7 years after high school.

These gaps narrow when we add the basic set of controls used in Tables 3-6, except for participants' shortfall in bachelor's degree receipt, which widens from 5 to 7 percentage points (Column 2). This moderate degree of attenuation combined with large gains in explained variance leads to the inference that controls are informative and that a sizable degree of selection on unobservables would be necessary to explain away Column 2 conditional gaps. Estimates of Oster's (2017) δ parameter are below R^2 values in Columns 2-4. If the true treatment effect on college credits earned within two years of high school is zero, selection into Knox Achieves based on unobservable determinants of credit gains within two years would have to be 4.6 times as informative as selection according to the basic X_{ist} vector components. Likewise, selection on unobservables would need to be more than 5 times as potent as selection on observables to explain conditional gaps in two-year college certificate receipt, and 9 times as potent to explain why Knox Achieves participants were 8 percentage points more likely to earn an associate's degree. The δ parameter is negative for bachelor's degree receipt in Column 2 of Table 7, in part because the negative estimated effect of program participation on bachelor's degree attainment widens from 5.3 to 6.9 percentage points when controls are added. That is, participants were *ex ante* more likely to complete a bachelor's degree than non-participants based on observable features and their rate of bachelor's degree completion fell short of expectations (we saw evidence of this in Table 2 as well). Nonetheless, controls considerably increase explained variance in this outcome, and it would presumably take a very large degree of unobservable aversion to four-year degrees to attribute the negative estimated effect of Knox Achieves participation to omitted variable bias.

Specifications reported in Column 3 of Table 7 expand the X_{ist} vector from 30 elements to over 800 by including quadratic functions of continuous variables and interactions between and among all binary and continuous variables other than school or cohort fixed effects. Under this more saturated and more flexible model, point estimates for college credit gains within two years

grow from 2.8 to 3.4, and the negative effect of participation on bachelor's receipt shrinks from 6.9 to 5.4 percentage points. Results for other outcomes change very little. Even though we added many more observable controls to the linear model, proportionate selection on unobservables would still have to be quite large to completely explain treatment-on-the-treated effect estimates.

Lastly, Column 4 reports results from a specification of Equation (1) with an intermediate degree of flexibility relative to baseline and saturated models. Specifically, we estimate Equation (1) using a set of controls identified by least absolute shrinkage and selection (LASSO). LASSO is known for improving prediction accuracy more so than for interpreting particular parameters, in part because shrunken coefficients are difficult to translate into policy predictions and more importantly because LASSO parameters may be sensitive to imperfect feature selection (Hansen et al. 2014). We follow the post-double-selection method prescribed by Hansen et al. (2014) to recover more stable and interpretable Equation (1) estimates of γ from a large, data-driven set of controls. Point estimates are little changed relative to the very flexible Column 3 specification, although the penalty to bachelor's degree receipt widens to 6.1 percentage points.

IV.C. Matching results

Treatment-on-the-treated estimates from Mahalanobis and propensity score matching procedures are reported in Table 8. The primary takeaway is that treatment effect estimates are similar under these two different matching schemes and—with some notable exceptions—very similar to conditional differences from linear estimates of Equation (1) for the effect of Knox Achieves participation. Columns 1 and 3 report matching results under Mahalanobis covariate-based matching, where treated students are paired with untreated students with quantitatively similar features. Columns 2 and 4 report treatment effects from propensity score matching, where the counterfactual to a Knox Achieves participant is a student with nearly the same propensity to engage with the program, but who did not participate because of choice or availability.

Columns 1-2 of Table 8 include Knox County non-participants in the donor pool, allowing participants to be matched to eligible students who chose not to participate. This construct allows for demonstrably better matching on observables (shown in Figure A1) but may

exacerbate selection on unobservables by identifying treatment effects from participation as well as willingness to engage with Knox Achieves when it was available. When the donor pool consists of Tennessee 12th graders from the classes of 2007-2011 including Knox County non-participants, we find that Knox Achieves students accumulate 3-4 more college credits within two years of high school, and in a departure from linear results, up to 3 more credits within four years of high school. Participant rates of certificate and associate's degree completion are 8-10 percentage points higher than the counterfactual, in agreement with linear treatment effect estimates. Bachelor's degree completion is 3-6 percentage points lower among participants than matched peers, a narrower gap than reported from most OLS models. Column 1-2 results for earnings 7 years after high school are notably smaller than comparable linear findings for participants: $829-1,014 in additional earnings per year, versus $1,457 reported in Table 3.

A plausible concern with the matching identification strategy is the idea that the choice dimension of participating in Knox Achieves is endogenous to future college success. Specifically, some program participants are paired with Knox County students who were eligible for Knox Achieves but chose not to participate for unobserved reasons that may include interest in community college. Results in Columns 3 and 4 report estimates from matching models that remove eligible non-participants from the donor pool. Counterfactual outcomes are drawn entirely from pre-program cohorts and Tennessee students outside of Knox County. Comparisons of Column 1 with 3 and Column 2 with 4 imply that this distinction has little bearing on inferences from matching-based identification, except for 7th year earnings, where there is disagreement across matching methods and donor pools as to the size and precision of the gap between Knox Achieves participants and other students. When we exclude Knox County non-participants from the donor pool, that gap ranges from $184-1,263, favoring non-participants and bookending Column 1-2 results where participants are more apt to be evaluated against their non-participating Knox County peers.

IV.D. Benefit-cost comparison

Eligibility for or participation in Knox Achieves is associated with an increased likelihood of receiving a certificate or associate's degree, and potentially, a decreased likelihood of receiving a bachelor's degree. The returns to a four-year degree dominate returns to an associate's degree, and starting in a community college sets students up to face transition costs if

they choose to transfer to a four-year institution. Our findings for in-state earnings and industries are limited to early-career years and potentially influenced by differential attrition and retention in UI-covered Tennessee jobs. Therefore, an open question about the efficacy of last-dollar scholarships that spotlight community colleges is whether the benefits from increased community college completion offset the reduction in bachelor's degree completion. In this section, we explore how the known costs of the program measure up to its potential benefits in terms of higher lifetime earnings for participants.

We note up front that the only benefit under consideration is changes in lifetime earnings associated with higher levels of education. Our benefit-cost computations omit any non-financial benefits of higher education, which are thought to be large and diverse, as well as the public cost of subsidizing higher education for more students.

We calculate Tennessee-specific lifetime earnings by education level following Blomquist et al. (2014), who apply coefficients from log earnings regressions using 2000 Census data, arriving at the earnings premium for different education levels including associate's degrees. We use the same regression equation, but with 2012-2016 data for Tennessee from the American Community Survey. This technique produces the following estimates of lifetime earnings, each in 2016 dollars: $1,334,758 for a high school diploma, $1,875,023 for an associate's degree, and $2,318,398 for a bachelor's degree.[12] Because the ACS data do not include certificates, we begin by assuming that a certificate returns lifetime earnings half-way between a high school diploma and an associate's degree. A certificate takes, on average, about half as long as an associate's degree to complete, and in a review of the literature on returns to sub-baccalaureate attainment, Belfield and Bailey (2017) report that the short-term earnings premium from certificate receipt is up to 46% of the return to an associate's degree. Recognizing widely varying returns to postsecondary certificates across studies, we also produce benefit-cost estimates where the return to certificate attainment is (1) one-fourth of the gain (relative to high school) of an associate's degree, (2) one-eighth of the gain of an associate's degree, and (3) zero—that is, that certificates yield the same lifetime earnings as a high school degree.

[12] Comparable national estimates from Carnevale et al. (2011) are $1,304,000 for a high school diploma, $1,727,000 for an associate's degree, and $2,268,000 for a bachelor's degree.

We compute the expected increase in earnings as the product of the increased likelihood of obtaining a given award multiplied by the gain in lifetime earnings from that award relative to high school. A further conversion is needed because the ACS measures education as the highest degree obtained, and our estimates thus far are for the likelihood of receiving credentials at all. Thus, we re-estimate linear models for the highest degree obtained within six years of high school. For linear eligibility results, reported in the top panel of Table 9, we estimate the effect of individual Knox Achieves eligibility in a model with school fixed effects, analogous to the specification in Table 3, Column 1. Knox Achieves is associated with an increase of 0.789 percentage points in the likelihood of attaining an associate's degree and no higher degree within six years. Thus, the expected benefit from more associate's degrees is:

E(benefit) = 0.000789 * (1,875,023 – 1,334,758) = 0.078 * 540,265 = 4,263

By a similar calculation, the expected per-participant benefit from higher likelihood of certificate attainment is $1,353, assuming that a postsecondary certificate is worth half of an associate's degree. And the expected loss in earnings from a lower likelihood of attaining a bachelor's degree is -$4,997, meaning that the net change in expected earnings for Knox Achieves participants is $619.

As mentioned earlier, 55 percent of senior-year participants enroll in a community college with Knox Achieves, and the cost to the funder of this last-dollar scholarship is around $1,000 per enrolled participant per year. We assume that this cost is measured in 2009 dollars, the first full year of scholarship, an amount equal to $1,119 in 2016 dollars (as benefits are measured in 2016 dollars). Using the calculation that 55 percent of Knox Achieves participants receive the scholarship and enroll in community college, along with a maximum eligibility of five semesters (or 2.5 years), and a participation rate of 16.8% among eligible students, we calculate a potential cost of $1,119 * 0.55 * 2.5 * 0.168 = $258 per eligible student. For participants only, the expected cost is $1,538.

Therefore, the benefit-cost ratio is $619/258 = 2.40 under the preferred, conservative linear specification of attainment effects arising from eligibility. Note, however, that because of the imprecision of eligibility effects on bachelor's degrees, the benefit-cost ratio is much larger at the upper limit of confidence intervals for certificate, associate's, and bachelor attainment: 0.6,

1.0, and 0.3 percentage points, respectively. In that scenario, expected benefits per student are over $10,000 in lifetime earnings, more than 40 times the per-eligible-student cost.

Moving down the top panel of benefit-cost estimates, we find that the sign of the net return is also sensitive to assumptions about the value of postsecondary certificates. If these credentials are worth no more than a high school diploma, the expected drop in lifetime earnings per participant is 2.8 times the cost to the funder.[13]

Turning to the bottom panel of benefit estimates, we also find that results are very different under estimated attainment effects from participation rather than eligibility. There, Knox Achieves participation precedes certificate (and no higher) attainment 2.3 percentage points higher than expected, associate attainment 5.5 percentage points higher, and bachelor's attainment of 7.2 percentage points lower, as reported in Table 3. In this model, returns to certificates and associate degrees are dominated by estimated earnings penalties from lower bachelor's degree receipt, and the net expected change in earnings is at least 22 times larger than the per-participant cost.

Looking across benefit-cost models, changes in expected lifetime earnings arising from Knox Achieves participation are not conclusively positive or negative. Net benefits would be positive and potentially large if Tennessee's economy over the next several decades places an atypically high premium on associate's degrees and certificates, or more importantly, if true effects on bachelor's degree receipt are different than we estimate in the preferred, conservative linear model (such as they are in some matching and less truncated analyses).

Another important caveat to recognize is that net benefits, either positive or negative, come with notable distributional effects. Tables 4-6 report evidence that students with lower *ex ante* college engagement are more likely to graduate with a bachelor's degree than they would otherwise, as are moderately low-income students, and non-white students who are underrepresented among the state's college graduates. Given low program costs, expected benefits for these students are unambiguously positive. We do not observe program spending for individual students, but benefit-cost computations would likely find a greater return for lower-

[13] If certificates were equivalent to associate's degrees in terms of the lifetime earnings premium over a high school degree, the benefit-cost ratio as computed in the top panel of Table 9 would be -0.66.

achieving students, as these participants tend to substitute fewer bachelor's degrees for two-year college awards with lower lifetime earnings. By contrast, we would expect larger negative returns among higher-income and higher-achieving students through last-dollar programs like Knox Achieves. These students collect more from the program in last-dollar aid and tend to exhibit a larger absolute shortfall in bachelor's degree completion six years after high school.

An additional caveat that bears repeating is that many potential costs and benefits are omitted from this analysis. For example, the decision to attend community college or university more than six years after high school is not included, nor are any delayed effects on bachelor's completion after six years. We ignore costs to the state government of providing additional funding to community colleges as well as any individual-level costs, including nonmonetary costs, not covered by the program. Nonmonetary benefits of higher education are also omitted. Benefits of each level of attainment are assumed to be uniform, ruling out the possibility of heterogeneous benefits that could correspond with student interest and aptitude for different community college or university programs. Any benefits of multiple credentials (two distinct certificates, for example, or a certificate and an associate's degree) or graduate degrees are omitted by our focus on highest undergraduate attainment. All the true costs and benefits of the program are not known, and these additional considerations further cloud our expectations about the net return to Knox Achieves participation.

V. Conclusion

In this study, we estimate the medium-term effects of a low-cost last dollar scholarship, Knox Achieves, on college completion up to 6 years after high-school graduation as well as in-state UI-covered earnings up to 9 years after high school. Key elements of Knox Achieves—universal place-based eligibility and last-dollar support—match statewide programs that followed in Tennessee and elsewhere throughout the United States. Estimated effects vary in magnitude across different approaches, but a consistent story emerges where the introduction of Knox Achieves led to more persistence and completion at two-year community colleges, heterogeneous effects on success at four-year colleges and universities, and short-term gains in employment and earnings alongside uncertain long-term returns.

On average, students eligible for Knox Achieves earned 1.6 more college credits within two years of high school but the gap disappears after four. Modest gains in credit accumulation nonetheless translate into large changes in the likelihood of completing a two-year college program. Eligible students were 1-3 percentage points more likely to earn a postsecondary certificate or associate's degree, which represent sizable improvements over control means of 2-4 percent, respectively. They were no more likely to complete a bachelor's degree, however, although college completion effects varied widely across student subgroups. Moderately low-income students, lower-achieving students, and black and Hispanic students were significantly *more* likely to complete a bachelor's degree if they had access to free community college through Knox Achieves, whereas more advantaged groups of students were *less* likely to finish a bachelor's degree, with varying degrees of precision. Apparent substitution for a two-year college education over a four-year university education was most pronounced for higher-achieving, higher-income students, who stood to gain more financial aid from the program. Less advantaged students who benefitted from access to Knox Achieves may have been on the fence about going to college at all, more so than starting at a two-year versus a four-year school.

More generous first-dollar scholarship programs that cover four-year schools as well as community colleges have been shown to increase college attainment by much more than Knox Achieves. The increase in the likelihood of receiving a bachelor's degree is 7.4 percentage points for the Kalamazoo Promise (Bartik et al., 2019) and 10.7 percentage points for the El Dorado Promise (Swanson and Ritter, 2018). The costs of guaranteeing first-dollar aid, however, are much higher than comparable costs from last-dollar Knox Achieves and its successor the Tennessee Promise. Kalamazoo Promise spent $17,620 per eligible student (Bartik et al., 2016, Table 2), versus $1,538 for Knox Achieves. Bartik et al. (2016) find that the likely benefits from higher lifetime earnings, driven by gains in bachelor's degree receipt, outweigh the costs 4.66 times (their Table 5). Page et al. (2018) estimate a benefit-cost ratio of Pittsburgh Promise equal to 1.35 based on gains in short-term college enrolment and persistence. Benefit-cost ratios for last-dollar Knox Achieves are far too inconclusive to evaluate net returns against these more costly Promise models, and whether higher lifetime earnings outweigh modest program costs will hinge on the extent to which students are deterred or delayed from completing a bachelor's degree, as well as future returns to certificates and associate degrees.

Our findings suggest that a low-cost, last-dollar promise of free community college can raise community college attendance and completion for participants regardless of income or aptitude, and can improve bachelor's degree attainment for underrepresented students or those who would not be expected to persist in college. At the same time, however, we find evidence supporting the idea that raising the incentives to start college in the two-year rather than four-year college sector lowers bachelor's degree attainment for some students, and in particular, higher-achieving, lowest-income students.

Uncertainty around highest degree attainment has economic implications for last-dollar programs modeled after Knox Achieves, including Tennessee Promise and several subsequent state initiatives, all of which share the premise that free college will support workforce development in an advancing economy. In order to do so unambiguously, the message of free college that motivates students to go to college at all should be paired with efforts to support students with transfer intentions through bachelor's degree completion.

In the years since the Knox Achieves study population completed high school, many statewide efforts have evolved in parallel to the expansion of the Knox Achieves, including K-12 reforms stemming from Race to the Top and the introduction of the "Drive to 55" postsecondary attainment goal. Also notably, a statewide system of transfer articulation agreements between community colleges and four-year universities was formalized, which should in principle ease student transitions between college sectors (Jenkins et al., 2018). It remains to be seen if such transfer pathways are an effective complement to free community college programs in practice, although our findings suggest that strong links between tertiary sectors will be critical to their success.

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Table 1. Student summary statistics, by Knox Achieves participation

Variable	(1) All Tennessee 12th Graders	(2) Knox County Knox Achieves participants	(3) Knox County non-participants
Seamlessly enrolled in college (0,1)	0.48	0.75	0.49
Attained a postsecondary certificate within 4 years (0,1)	0.02	0.12	0.03
Attained an associate's degree within 4 years (0,1)	0.04	0.15	0.05
Attained a bachelor's degree within 6 years (0,1)	0.19	0.17	0.25
In-state earnings one year after high school (000s)	4.47	5.44	4.60
	(6.02)	(5.57)	(6.22)
In-state earnings seven years after high school (000s)	15.96	17.84	14.95
	(18.11)	(16.01)	(18.24)
Female (0,1)	0.5	0.61	0.47
Hispanic (0,1)	0.23	0.22	0.14
Black (0,1)	0.03	0.02	0.02
White, non-Hispanic (0,1)	72.36	74.68	81.34
Free lunch for at least three years, 8th-12th grade (0,1)	17.15	31.44	13.1
Any free lunch, 8th-12th grade (0,1)	38.08	47.56	31.53
Any reduced-price lunch, 8th-12th grade (0,1)	0.12	0.2	0.11
ACT composite	17.36	18.17	17.11
	(3.66)	(4.00)	(3.33)
Average standardized EOC	0.06	0.18	0.28
	(0.83)	(0.66)	(0.97)
N (students)	307,798	2,109	18,105

Notes: Standard deviations are in parentheses below continuous-valued means. The sample includes 12th grade students throughout Tennessee, academic years 2006-2007 through 2010-2011. Other variables included in the analysis: the number of schools, districts, and counties a student attended since 8th grade, junior and senior year earnings, ACT subscores, EOC subject scores, an indicator for having repeated the 12th grade, indicators for cohort, indicators for missing ACT and EOC scores, and annual county unemployment rates. For college outcomes, samples exclude students who enrolled in non-THEC institutions.

Table 2: Balancing tests of *ex ante* expectations by Knox Achieves availability or participation

	(1)	(2)	(3)	(4)
Measure of treatment	Post-2008 Knox County	Individual KA participation indicator	Post-2008 Knox County	Individual KA participation indicator
County fixed effects	Yes	Yes	No	No
School fixed effects	No	No	Yes	Yes
Fitted THEC college credits within years	2.80***	2.02	1.60	1.12
	(0.85)	(1.76)	(1.01)	(2.01)
Fitted THEC college credits within 4 years	6.48***	3.95	3.36	2.05
	(1.76)	(3.64)	(2.09)	(4.22)
Fitted certificate attainment within 4 years	-0.001**	-2.0E-04	0.003***	0.001
	(0.000)	(0.001)	(0.001)	(0.001)
Fitted associate's degree attainment within 4 years	-0.006***	-0.001	1.00E-03	0.003
	(0.002)	(0.004)	(0.002)	(0.004)
Fitted bachelor's degree attainment within 6 years	0.053***	0.024	0.024	0.010
	(0.013)	(0.027)	(0.015)	(0.030)
Fitted earnings 7 years after high school	45.20	723.91	173.47	705.32
	(233.76)	(596.74)	(276.81)	(587.23)
Students	307,727	307,727	307,727	307,727

Notes: The table lists γ estimates from Equation (1), where observed outcomes are substituted with fitted predictions from pre-program estimates (classes of 2007 and 2008). Outcomes are listed at left. Columns 1 and 3 reports results from a version of Equation 1 where the Knox Achieves treatment is a simple indicator for seniors in Knox County schools after the program was initiated. Columns 2 and 4 report results from a specification of Equation 1 where treatment status is assigned to Knox County seniors who signed up for Knox Achieves in the fall of their senior year. Standard errors are in parentheses below each coefficient.

*** significant at 1 percent, ** significant at 5 percent, * significant at 10 percent

Table 3: Average intent-to-treat and treatment-on-the-treated effect estimates

	(1)	(2)
Measure of treatment	Post-2008 Knox County	Individual KA participation indicator
School fixed effects	Yes	Yes
THEC college credits within 2 years	1.62***	2.48***
Control mean: 17.75	(0.42)	(0.18)
THEC college credits within 4 years	0.76	-0.54*
Control mean: 32.22	(0.61)	(0.31)
Postsecondary certificate attainment within 4 years	0.027***	0.080***
Control mean: 0.016	(0.002)	(0.002)
Postsecondary associate's degree attainment within 4 years	0.010***	0.090***
Control mean: 0.036	(0.001)	(0.002)
Postsecondary bachelor's degree attainment within 6 years	-0.005	-0.072***
Control mean: 0.190	(0.004)	(0.003)
In-state earnings 7 years after high school	732.70***	1456.49***
Control mean: 15,976	(146.28)	(73.21)
Treated students	12,343	2,038
All students	307,727	307,727

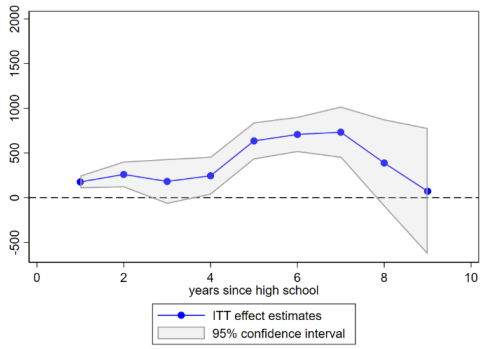
Notes: The table lists γ estimates from Equation 1, ITT and ATT estimates of the effect of Knox Achieves availability or participation on college persistence, attainment, and earnings. Outcomes are listed at left. Column 1 reports results from a version of Equation 1 where the Knox Achieves treatment is a simple indicator for seniors in Knox County schools after the program was initiated. Column 2 reports results from a specification of Equation 1 where treatment status is assigned to Knox County seniors who signed up for Knox Achieves in the fall of their senior year. Additional controls include cohort fixed effects, school fixed effects, observable student characteristics, school composition, and the county unemployment rate. Samples include students with no record of college enrollment, whose postsecondary outcomes are imputed to be zero. The top 5% of program participants, in terms of credit accumulation, are excluded. Robust standard errors, in parentheses below point estimates, allow for clustering by county.

*** significant at 1 percent, ** significant at 5 percent, * significant at 10 percent

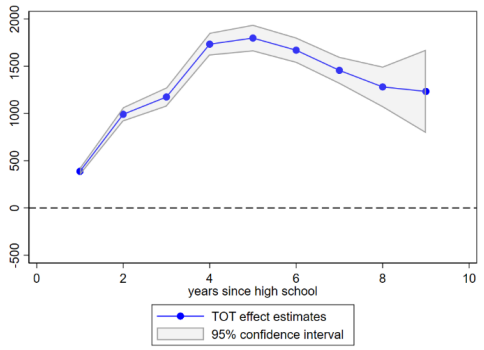
Figure 3: ITT and ATT effect estimates on earnings, by years since high school

In-state earnings 1-6 years after high school (including zero if missing)

I. Estimated effect of Knox Achieves availability

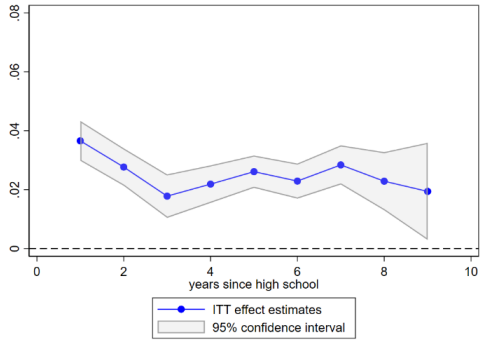


II. Estimated effect of Knox Achieves participation

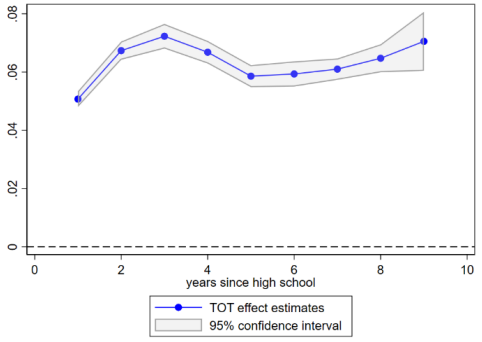


Any in-state earnings 1-9 years after high school (0,1)

III. Estimated effect of Knox Achieves availability

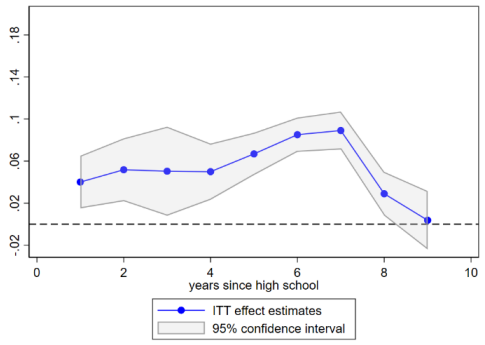


IV. Estimated effect of Knox Achieves participation

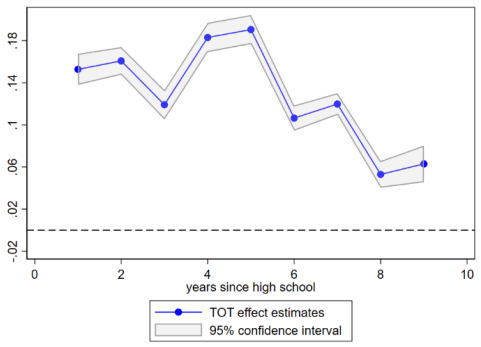


Log in-state earnings 1-9 years after high school (if non-missing)

V. Estimated effect of Knox Achieves availability



VI. Estimated effect of Knox Achieves participation

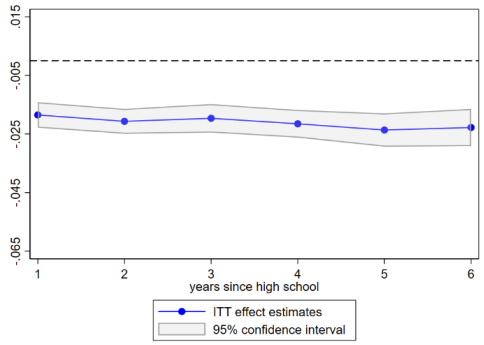


Figures display Equation (1) point estimates and confidence intervals for ITT estimated effects of Knox Achieves availability (panels I, III, V) and participation (II, IV, VI).

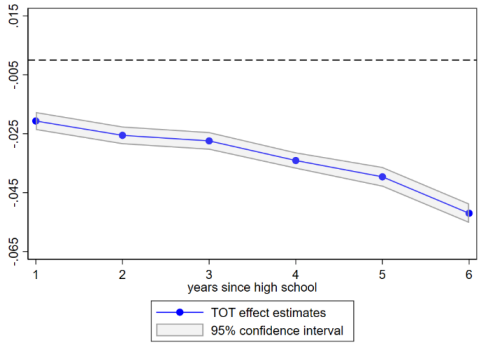
Figure 4: ITT and ATT effect estimates on attrition and industry, by years since high school

Attrition from in-state earnings 1-6 years after high school (0,1)

I. Estimated effects of Knox Achieves availability

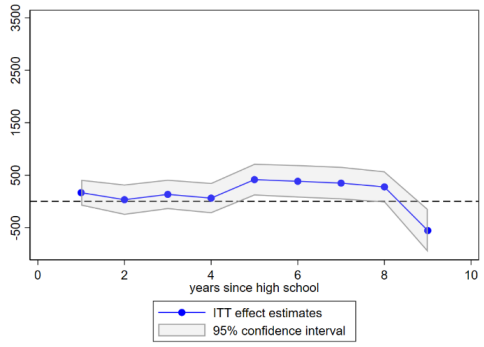


II. Estimated effects of Knox Achieves participation

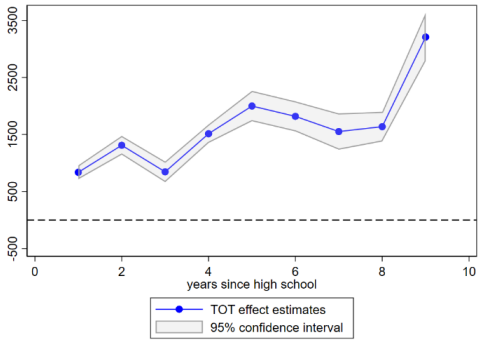


Industry score 1-9 years after high school (excluding zero and missing)

III. Estimated effects of Knox Achieves availability



IV. Estimated effects of Knox Achieves participation



Figures display Equation (1) point estimates and confidence intervals for ITT estimated effects of Knox Achieves availability (panels I, III) and participation (II, IV).

Table 4: Average intent-to-treat effect estimates, by free lunch status

	(1)	(2)	(3)
Measure of treatment	Post-2008 Knox County	Post-2008 Knox County	Post-2008 Knox County
Years eligible for free lunch, 8th-12th grade	None	1-2	3+
THEC college credits within 2 years	1.88***	2.71***	1.47***
	(0.53)	(0.42)	(0.41)
	22.34	11.15	9.21
THEC college credits within 4 years	0.93	4.22***	1.43***
	(0.84)	(0.56)	(0.44)
	41.27	19.34	15.17
Postsecondary certificate attainment within 4 years	0.033***	0.025***	0.011***
	(0.003)	(0.002)	(0.001)
	0.020	0.013	0.009
Postsecondary associate's degree attainment within 4 years	0.013***	0.014***	-0.011***
	(0.002)	(0.002)	(0.002)
	0.046	0.023	0.014
Postsecondary bachelor's degree attainment within 6 years	-0.004	0.018***	-0.011***
	(0.006)	(0.003)	(0.004)
	0.254	0.098	0.070
In-state earnings 7 years after high school	149.22***	129.91*	194.51
	(42.32)	(78.03)	(136.40)
	4,602.40	4,538.00	3,892.97
Treated students	7,619	1,799	2,925
All students	190,543	64,424	52,760

Notes: The table lists γ estimates from Equation 1, ITT estimates of the effect of Knox Achieves availability or participation on college persistence, attainment, and earnings. Robust standard errors, in parentheses below point estimates, allow for clustering by county. Control means are listed below standard errors.

*** significant at 1 percent, ** significant at 5 percent, * significant at 10 percent

Table 5: Average intent-to-treat effect estimates, by achievement and *ex ante* persistence

	(1)	(2)	(3)	(4)
	Above median		Below median	
	Expected college credits	End-of-course achievement	Expected college credits	End-of-course achievement
THEC college credits within 2 years	2.48***	1.50***	1.16***	1.64***
	(0.62)	(0.53)	(0.38)	(0.41)
	27.57	26.79	8.18	8.86
THEC college credits within 4 years	1.13	0.015	1.90***	2.49***
	(1.18)	(0.94)	(0.50)	(0.55)
	50.50	49.51	14.38	15.20
Postsecondary certificate attainment within 4 years	0.0410***	0.037***	0.002**	0.011***
	(0.003)	(0.003)	(0.001)	(0.001)
	0.024	0.022	0.009	0.011
Postsecondary associate's degree attainment within 4 years	0.015***	0.014***	(0.003)	0.004***
	(0.002)	(0.002)	(0.002)	(0.001)
	0.055	0.051	0.018	0.021
Postsecondary bachelor's degree attainment within 6 years	-0.005	-0.010	0.009**	0.010***
	(0.008)	(0.007)	(0.004)	(0.004)
	0.316	0.312	0.067	0.071
In-state earnings 7 years after high school	301.19*	137.56	1017.49***	1180.20***
	(180.22)	(164.82)	(187.93)	(165.00)
	18,240	182,70	13,770	13,720
Treated students	7,951	7,303	4,392	5,040
All students	153,832	153,840	153,895	153,887

Notes: The table lists γ estimates from Equation 1, ITT estimates of the effect of Knox Achieves availability on college persistence, attainment, and earnings. Robust standard errors, in parentheses below point estimates, allow for clustering by county. Control means are listed below standard errors

*** significant at 1 percent, ** significant at 5 percent, * significant at 10 percent

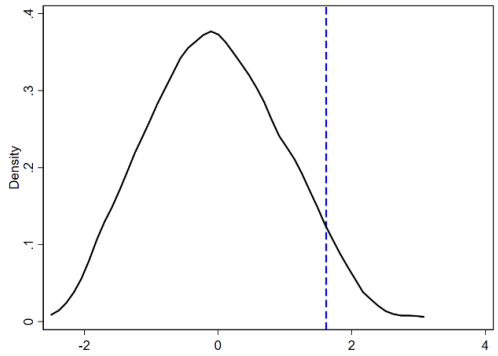
Table 6: Average intent-to-treat effect estimates, by race, Hispanic ethnicity, and gender

Subsample	(1) Black	(2) Hispanic	(3) White	(4) Women	(5) Men
THEC college credits within 2 years	2.14***	5.46***	1.62***	1.47***	1.83***
	(0.37)	(0.52)	(0.49)	(0.46)	(0.39)
	13.40	10.48	19.29	20.71	14.79
THEC college credits within 4 years	2.85***	4.54***	0.89	0.53	1.14*
	(0.45)	(0.97)	(0.79)	(0.67)	(0.61)
	24.16	19.01	35.01	37.47	26.96
Postsecondary certificate attainment within 4 years	0.004***	0.036***	0.030***	0.024***	0.029***
	(0.001)	(0.003)	(0.002)	(0.002)	(0.002)
	0.005	0.010	0.021	0.018	0.015
Postsecondary associate's degree attainment within 4 years	0.010***	-0.019***	0.012***	0.009***	0.011***
	(0.002)	(0.005)	(0.002)	(0.002)	(0.001)
	0.010	0.021	0.046	0.046	0.026
Postsecondary bachelor's degree attainment within 6 years	0.013***	0.030***	-0.003	-0.002	-0.006
	(0.004)	(0.009)	(0.005)	(0.006)	(0.004)
	0.131	0.114	0.210	0.221	0.159
In-state earnings 7 years after high school	757.03***	1,644.06***	823.75***	-8.72	1,476.47***
	(175.39)	(430.01)	(182.83)	(150.86)	(191.75)
	13,940	11,690	16,900	14,620	17,330
Treated students	1,952	339	9,826	5,980	6,363
All students	72,116	9,463	222,663	153,838	153,889

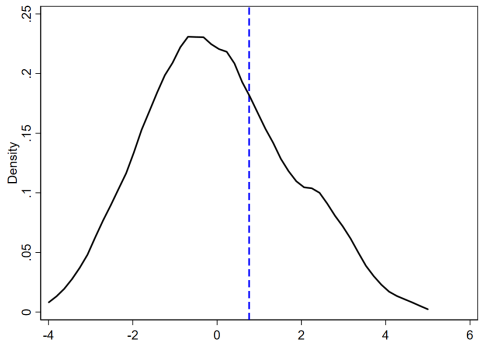
Notes: The table lists γ estimates from Equation 1, ITT estimates of the effect of Knox Achieves availability on college persistence, attainment, and labor market measures. Robust standard errors, in parentheses below point estimates, allow for clustering by county. Control means are listed below standard errors.
*** significant at 1 percent, ** significant at 5 percent, * significant at 10 percent

Figure 3: Permutation results for Equation (1): ITT effects of Knox Achieves versus placebos

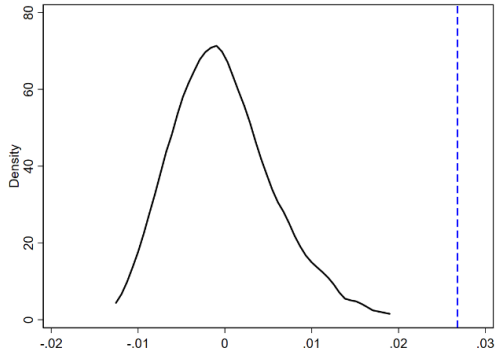
I. College credits within two years (9.7% greater)



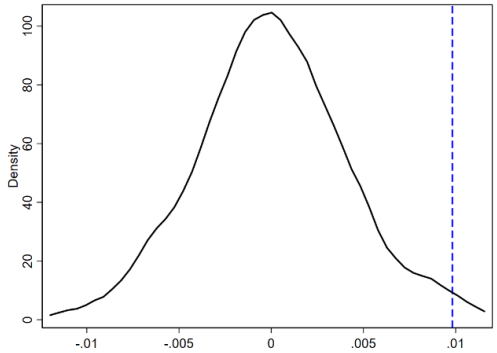
II. College credits within four years (66.7% greater)



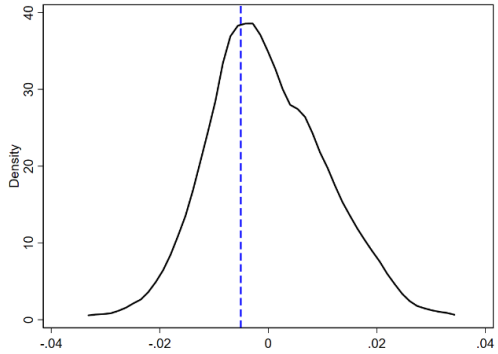
III. Certificate attainment (0.0% greater)



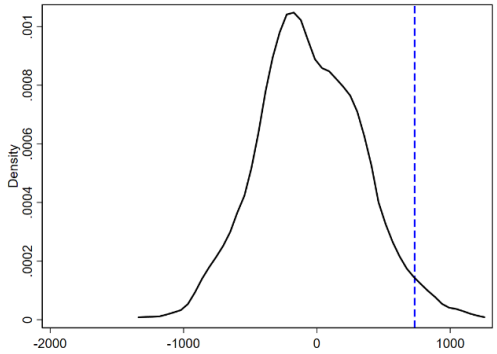
IV. Associate degree attainment (2.0% greater)



V. Bachelor's degree attainment (64% greater)



VI. In-state earnings seven years after high school (6.0% greater)



Each panel illustrates the distribution of 300 iterations of Equation (1) results for Knox Achieves availability, with treated schools randomly reassigned across the state. Estimates of true ITT effects are marked with vertical dashed lines. The share of placebo estimates that are larger, in absolute value, than ITT estimates are listed in parentheses with each panel heading.

Table 7: Robustness of average treatment on the treated effect estimates

	(1)	(2)	(3)	(4)
Measure of treatment	Individual KA participation indicator	Individual KA participation indicator	Individual KA participation indicator	Individual KA participation indicator
Controls	Cohort fixed effects	Basic	Flexible	Selected features among flexible set
THEC college credits within 2 years	4.16***	2.78***	3.38***	2.92***
	(0.43)	(0.53)	(0.53)	(0.53)
Oster delta estimate		4.60	6.70	5.05
R-squared	<0.01	0.27	0.31	0.28
THEC college credits within 4 years	1.96**	-0.45	1.35	0.77
	(0.89)	(0.98)	(0.98)	(0.97)
Oster delta estimate		-0.56	4.34	1.69
R-squared	<0.01	0.27	0.31	0.29
Postsecondary certificate attainment within 4 years	0.098***	0.077***	0.075***	0.074***
	(0.002)	(0.003)	(0.003)	(0.003)
Oster delta estimate		5.37	4.76	4.87
R-squared	<0.01	0.03	0.03	0.03
Postsecondary associate's degree attainment within 4 years	0.097***	0.084***	0.084***	0.081***
	(0.005)	(0.005)	(0.005)	(0.005)
Oster delta estimate		8.94	7.60	7.78
R-squared	<0.01	0.04	0.05	0.04
Postsecondary bachelor's degree attainment within 6 years	-0.053***	-0.069***	-0.054***	-0.061***
	(0.008)	(0.009)	(0.009)	(0.009)
Oster delta estimate		-27.58	17.12	-388.43
R-squared	<0.01	0.19	0.22	0.20
In-state earnings 7 years after high school	1,699***	1,352***	1,129***	1,196
	(422)	(424)	(433)	(425)
Oster delta estimate		7.50	4.02	5.12
R-squared	<0.01	0.100	0.111	0.101
Treated students	1,917	1,917	1,917	1,917
All students	300,114	300,114	300,114	300,114

Notes: The table lists γ estimates from Equation 1, ATT estimates of the effect of Knox Achieves availability or participation on college persistence and attainment measures. Robust standard errors, in parentheses below point estimates, allow for clustering by county.
*** significant at 1 percent, ** significant at 5 percent, * significant at 10 percent

Table 8. Matching results: Knox Achieves participation and postsecondary outcomes

	(1)	(2)	(3)	(4)
Control reservoir includes Knox County non-participants	Yes	Yes	No	No
Matching method	Mahalanobis	Propensity score	Mahalanobis	Propensity score
THEC college credits within 2 years	3.04	4.42	4.00	4.64
	(0.67)	(0.79)	(0.71)	(0.79)
THEC college credits within 4 years	0.79	2.88	2.44	2.96
	(1.24)	(1.42)	(1.30)	(1.42)
Postsecondary certificate attainment within 4 years	0.076	0.100	0.089	0.100
	(0.009)	(0.008)	(0.008)	(0.008)
Postsecondary associate's degree attainment within 4 years	0.081	0.089	0.087	0.087
	(0.010)	(0.010)	(0.009)	(0.010)
Postsecondary bachelor's degree attainment within 6 years	-0.061	-0.028	-0.045	-0.029
	(0.012)	(0.012)	(0.012)	(0.012)
In-state earnings 7 years after high school	829.47	1013.69	183.97	1263.40
	(534.96)	(568.06)	(550.01)	(568.05)
All students on support	2,038	2,038	2,038	2,038
Treated students on support	307,183	304,643	296,859	294,422

Notes: The table lists Mahalanobis and propensity score matching results for postsecondary outcomes (average treatment on the treated, or ATT). We use a nearest-neighbor matching estimator, matching each Knox Achieves participant to one non-participant, with replacement in terms of the Mahalanobis distance metric or the propensty score. Standard errors for Mahalanobis matching are computed according to Abadie and Imbens (2006). Propensity score estimates accommodate a 2 percentage-point caliper of participation propensity and trim the top one percent of Knox Achieves participants in terms of participation propensity.

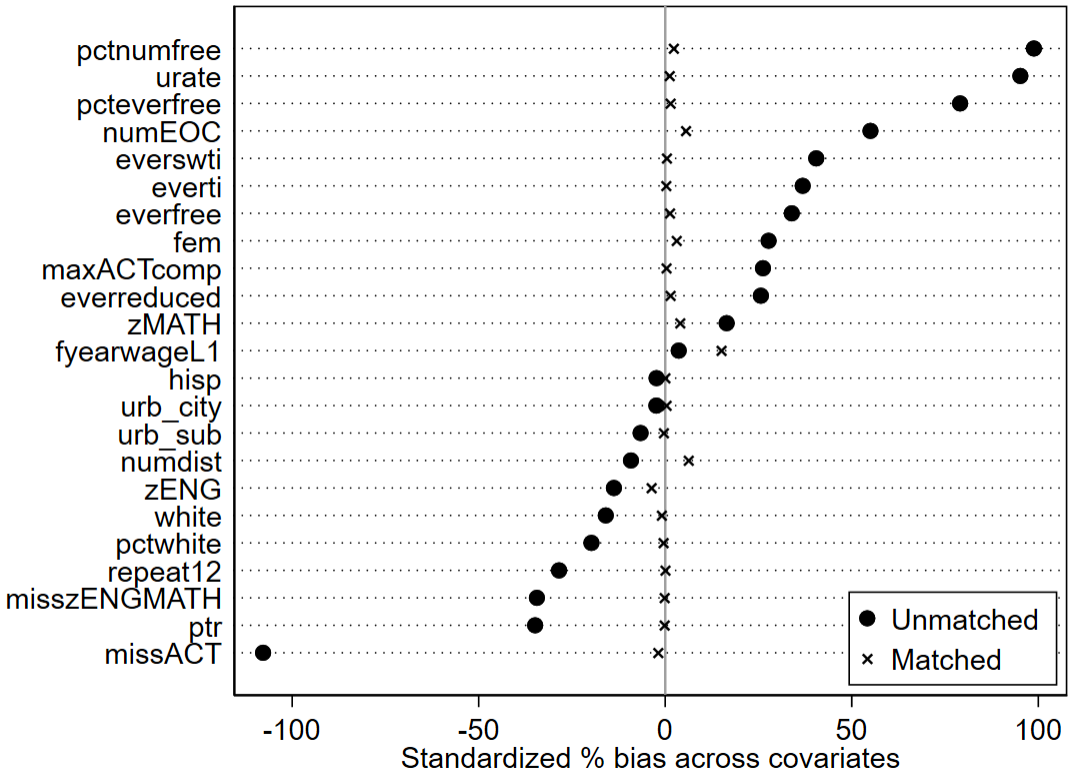
Table 9. Estimated Benefits and Costs of Knox Achieves Eligibility and Participation

	Expected Change in Lifetime Earnings (in thousands)				Benefit Cost Ratio
	Certificate	Associate's	Bachelor's	Total	
Linear estimates: Six-year highest attainment	0.0050	0.0079	-0.0051		
(Table 3, Column 1 specification)	(0.0007)	(0.0010)	(0.0043)		
Certificate Benefit = 1/2 Associate's	$1,353	$4,263	-$4,997	$619	2.40
Certificate Benefit = 1/4 Associate's	$677	$4,263	-$4,997	-$58	-0.22
Certificate Benefit = 1/8 Associate's	$338	$4,263	-$4,997	-$396	-1.53
Certificate Benefit = 0	$0	$4,263	-$4,997	-$734	-2.84
Linear estimates: Six-year highest attainment	0.0234	0.0550	-0.0721		
(Table 3, Colunm 2 specification)	(0.0008)	(0.0010)	(0.0027)		
Certificate Benefit = 1/2 Associate's	$6,327	$29,715	-$70,881	-$34,840	-22.64
Certificate Benefit = 1/4 Associate's	$3,163	$29,715	-$70,881	-$38,003	-24.70
Certificate Benefit = 1/8 Associate's	$1,582	$29,715	-$70,881	-$39,585	-25.73
Certificate Benefit = 0	$0	$29,715	-$70,881	-$41,167	-26.76

Notes: The table reports estimates of benefits to program participation in terms of lifetime earnings. In the top panel, linear estimates replicate the Table 3, Colum 1 OLS model, but for highest certificate or degree attainment within 6 years of high school. Robust standard errors, in parentheses below point estimates, allow for clustering by county. The bottom panel reports highest attainment estimates arising from the participation model (Table 3, Column 2 specification). Costs of program participation are assumed to be $1,538 in the bottom panel, roughly the value of average program spending per student-year, in 2016 dollars, if each student attended for the maximum 5 semesters, or 2.5 years. Costs of eligibility are $1,538*0.168 = $257, which accounts for 16.8% participation rates among eligible students. Benefits are Tennessee-specific estimated lifetime earnings returns over a high school degree derived from the 2012-2016 ACS (Blomquist et al., 2014).

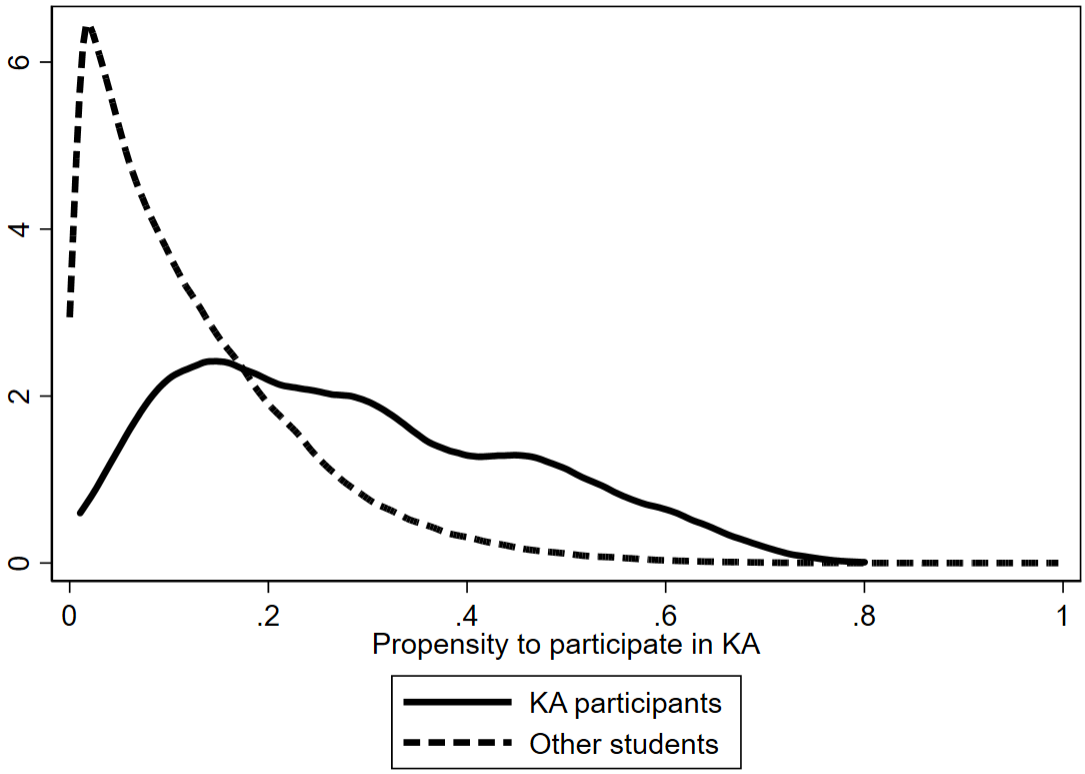
Appendix: Supplementary Figures and Results

Figure A1. Unmatched and matched balance in student and school observable features



Notes: The figure depicts standardized differences in observed student and school characteristics within unmatched (diamonds) and matched (x markers) samples. Treatment and control observations were matched by minimizing Mahalanobis distance metrics between vectors of these control variables.

Figure A2. Knox Achieves participation propensity



Notes: The figure depicts kernel densities of the estimated propensity to participate in Knox Achieves for actual participants (solid line) and non-participants (dashed line). Propensities were estimated by logit for Knox County 12th graders in the classes of 2009-2011. Factors included in the logit model included student characteristics (measures of demographics and need), student achievement on end-of-course and ACT exams, and school composition (including, among other controls, the percent white and the percent ever qualifying for free lunch).