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

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Celeste K. Carruthers
University of Tennessee

William F. Fox
University of Tennessee

Christopher Jepsen
University College Dublin, IZA, and CES-Ifo

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Abstract

We examine the effect of a local financial aid 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, and a heterogeneous change in the likelihood of attaining a bachelor's degree. Moderately low-income and lower-achieving students, who perhaps had the greatest need that could be fulfilled by the last-dollar program, were significantly more likely to complete a bachelor's degree if they had access to Knox Achieves. We also find that Knox Achieves is associated with higher in-state earnings and participation in more lucrative industries up to 9 years after high school. These short-term labor market effects are driven by differential retention in state Unemployment Insurance records.

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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. Unlike the California plan, 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.[4] 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). 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%[5] to 55% by the year 2025.

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

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 impact 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, highly promoted, 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 insignificant change in the likelihood of attaining a four-year college degree within 6 years of high school, and higher earnings 7-9 years after high school. 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 lower-income students with above-median high school achievement 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.

In terms of short-term earnings, Knox Achieves eligibility appears to significantly raise in-state earnings covered by Unemployment Insurance (UI) 4-8 years after high school, tapering in the 9th year. We delve into two potential mechanisms pushing earnings up, and we find that Knox Achieves eligibility and participation are associated with (1) a higher likelihood of any employment in UI-covered jobs, and (2) employment in more lucrative industries, as measured by average quarterly earnings throughout the United States.

Except where noted otherwise, our 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. Preferred specifications are well balanced and we do not detect consistently significant OLS or matching "effects" on pseudo-outcomes estimated from pre-program predictions. Matching treatment effects are similar in magnitude to linear difference-in-difference estimates and robust to variations on our matched pair procedure.

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. At the same time, evident substitution from four-year schools to two-year community colleges, and lower bachelor's degree completion among higher-achieving, 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.

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 80 local place-based programs that meet this broad definition (Upjohn Institute, 2016), 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., 2015; Page et al., 2018). Regarding college completion, Bartik et al (2015) 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 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. (2015) 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 observe 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 credit accumulation two years after high school. 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.

And third, 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 alongside declines in four-year college completion.

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 most 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 14% 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 estimate effects of Knox Achieves on earnings 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 their industry that year, or as a weighted average if they worked in multiple industries.

Knox Achieves participants completed 4-6 more college credits within two years than their peers in Knox County and the surrounding state, although the advantage over Knox County non-participants narrowed to less than 1 credit after four years. Participants also 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 slightly less likely to appear in a four-year college or university within six years of completing high school. Participants enroll in four-year institutions at a rate of 40 percent, versus 41-42 percent for other students. The gap in bachelor's degree completion is greater, with 17 percent of participants receiving 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 are roughly equal across the three groups, with an average around $6,500 per year.

Looking to student characteristics, the profile of a typical Knox Achieves student is one who is socioeconomically disadvantaged but performing on par in terms of standardized achievement. Program participants are more likely to be female, non-white, and 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's 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.[6] 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.

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 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 3.3% of participants excluded; this is the product of the 5 percentage-point negative effect on enrolling outside of Tennessee's public higher education systems and the 65% nationwide graduation rate from

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

private nonprofit institutions (Musu-Gillette, et al., 2017). Results are also reported without truncation.

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.[7] 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.

[7] 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).

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 quantitatively 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 exams, 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 1 depicts the average standardized gap in observable features before (diamonds) and after (x markers) 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 other students.[8]

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 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

[8] 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.

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 2 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 orthogonal to 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 predictions on all observations 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 fully 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 and program completion.

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 exclude school fixed effects, and the pattern of results indicates that *ex ante* predictions from that specification are fairly unbalanced. In the absence of Knox Achieves, there would have been a strong tendency for treated students to accumulate more college credits and attain college degrees at a higher rate than the counterfactual. However, this tendency dissipates once we control for fixed but unobserved properties of treated schools (as seen in Columns 3-4), which is why our preferred specification of Equation (1) includes school fixed effects. Focusing on Column 3-4 balancing tests, we find just one statistically significant difference (at the five percent level) in expected college 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).

IV.B. Equation (1) results

Table 3 lists difference-in-difference 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 coefficient estimates for a broad eligibility indicator (equal to one for all 2009-2011 Knox County high school seniors), meaning that γ estimates in Column 1 can be interpreted as intent-to-treat estimates. We find that Knox Achieves availability preceded a countywide 1.7-credit rise in college credits two years after high school, along with a 2-percentage point rise in four-year college attendance, a 1-3 point rise in timely postsecondary certificate or associate's degree attainment, and a statistically insignificant 0.5-percentage point fall in bachelor's degree attainment within six years of high school.

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 2.6 credit gain over non-participants after two years (14.5% of the control mean), no significant difference 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, outstrip 7-percentage-point reductions in the likelihood of four-year degree receipt, such that the likelihood of any college credential rose for program participants by one percentage point (3.6%) relative to non-participants.

Figure 3 contains the relationship between Knox Achieves and unconditional earnings levels for each year since finishing high school. Specifically, Panel A contains the regression coefficients for Knox Achieves eligibility. Here, we see a positive association between Knox Achieves eligibility and earnings starting four years after high school. The highest benefit is around $500 per quarter, an effect of over 30 percent of mean quarterly earnings. The effect of Knox Achieves participation, shown in Panel B, is more than twice as large and grows steadily throughout the time period. This pattern of results is similar when we replace observed earnings with an industrial score equal to average U.S. earnings in an individual's industry, as shown in Figure 4. The industrial score is higher for workers in better-paying industries and can be interpreted as an individual's potential midcareer earnings in their current field, if the U.S. average is an accurate projection. With that in mind, Figure 4 suggests that Knox Achieves eligibility and/or participation are both associated with employment in better-paying industries after high school, more so over time. This is one mechanism potentially underlying Figure 3 results for earnings themselves.

Another potential mechanism is an increased likelihood of working at all in UI-covered occupations in Tennessee, which we illustrate evidence for in Figure 5. Following Grogger (2012), we define attrition from the earnings sample as the beginning of a terminal run of zero earnings. We then apply Equation (1) to the incidence of attrition 1-6 years following high school. Figure 5 plots coefficient estimates for the relationship between Knox Achieves and attrition from in-state work. Regardless of whether Knox Achieves is measured in terms of eligibility (Panel A) or individual-level participation (Panel B), the effect is similar: Knox

Achieves is associated with a reduction of attrition of at least three percentage points. However, the drop attrition is noticeably more pronounced when measuring individual-level participation in Knox Achieves. Higher earnings shown in Figure 3 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 better opportunities. Our ongoing work seeks to bound treatment effect estimates for earnings to account for potential program effects on employment and attrition.

As shown in Table 3, 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) 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 that this substitution was more pronounced for higher-income and higher-achieving students. Shifting preferences for where to start college, combined with our 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.

Focusing first 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 one or two years in that time (Column 2), and those who were eligible for at least three 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.

In general, the availability of Knox Achieves is associated with the most improvement for middle-income students (Column 2), compared with higher income (Column 1) or lower-income (Column 3) students. For example, the increase in any postsecondary attainment is highest for the middle income group, with an increase of 4.2 percentage points, compared to increases of one percentage point or less. 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 1.9 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 approximately 1.5 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 average standardized end-of-course achievement prior to high school exit, with Columns 1-3 for above the median and Columns 4-6 below. As in Table 4, each group is also divided by free lunch status as in Table 4, and each specification focuses on treatment effect estimates arising from county-level Knox Achieves availability. Although the results vary greatly across the columns, a general pattern is, again, that the strongest effects of Knox Achieves availability are for the middle-income group. The only negative effects are for high-achieving students (Columns 1-3),

and the only statistically significant effects are for low-income students (Column 3). Nearly all the effects are positive and significant for low-achieving students, regardless of free lunch status.

Table 6 also looks at results by ability, but the focus is now on individual level participation in Knox Achieves, or treatment-on-the-treated. For Column 1-2 results, we first estimate expected credit accumulation after four years as a function of observable student features for two pre-program cohorts (as in the Table 2 falsification test), and we then divide the sample at the median. Columns 3 and 4 divide the sample by end-of-course achievement tests as in Table 5. The results are not consistent across outcomes. Students with below-median ability benefitted more from Knox Achieves participation than others with respect to credits after four years and bachelor's degree completion, whereas higher-ability students benefited more with respect to certificate and associate's degree attainment. Participating students who we expect would earn below-median college credits in the absence of Knox Achieves realized larger credit gains than *ex ante* above-median participants, in both absolute terms and relative to control means. Below-median participants were significantly more likely to enroll in a four-year university at some point in the years after high school than non-participants with similarly weak college prospects, and they were 1.3 percentage points more likely to earn a bachelor's degree within six years of high school. This is the only subgroup of Knox Achieves participants who complete both two-year and four-year degrees at conditionally higher rates than their peers. Participants with expected college credits in excess of the median were less likely to enroll in or graduate from a four-year university and relatively more likely to attain a certificate or associate's degree instead. In other words, higher-ability 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 expense of bachelor's degrees.

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 on par with their non-participating peers in Knox County but socioeconomically more disadvantaged (Table 1). Nevertheless, Table 7 shows that they accumulated 3-5 more college credits than their cohorts at large, they were 10-11 percentage points more likely to attain a two-year credential, but they were 4 percentage points less likely to appear in a university in the years after high school and 5 percentage points less likely to receive a bachelor's degree.

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 (R^2 values are reported below standard errors) 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 5.2 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 four-year college enrollment and two-year college certificate receipt, and 9 times as potent to explain why Knox Achieves participants were 9 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 4.6 to 5.9 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 (we saw evidence of this in Table 2 as well) and their rate of bachelor's degree completion fell short of expectations. Nonetheless, controls considerably increase the degree of 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 2.9 to 3.6, estimates for credit gains within four years grow from an imprecise zero to a weakly significant 1.7, and the negative effect of participation on bachelor's receipt shrinks from 5.9 to 3.8 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. LASSO algorithms select between 47 and 108 controls for each outcome. Point estimates are little changed relative to the very flexible Column 3 specification, although the penalty to bachelor's degree receipt widens to 5.2 percentage points.

Looking across results from Tables 3 and 7, we conclude that Knox Achieves participation is likely responsible for college credit gains equivalent to about one 3-credit class after two years (but becoming indistinguishable from zero after four years), 8-percentage-point gains in certificate receipt, 9-percentage point gains in associate's degree receipt, with a possible decline in bachelor's degree completion of 5-7 percentage points (depending on the specification). Relaxing treatment group sampling bounds or controlling for a more flexible function of controls points to a slightly smaller tradeoff between two-year and four-year completion, although the direction and size of estimated treatment effects are still robust to a large degree to selection on unobservables.

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). 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 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 12^{th} 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 8-9 percentage points higher than the counterfactual, in agreement with linear treatment effect estimates. Bachelor's degree completion is 4 percentage points lower among participants than matched peers, a narrower gap than reported from most OLS models, and one that is not significantly different from zero in the Column 2 propensity score model.

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 address this concern by removing 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 perhaps for bachelor's degree receipt, 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. Under propensity score matching, that gap ranges from a statistically insignificant 2.7 percentage points to a significant 4.3 percentage points, both favoring non-participants and bookending comparable estimates from Mahalanobis matching.

Finally, we pursue a falsification test under the matching identification construct to gauge the extent to which one's college persistence and completion is predetermined by Knox County students' inherent propensity to participate in a last-dollar scholarship program. Specifically, we assign a pseudo-participation indicator equal to one for pre-program Knox County students with participation propensity greater than the 75th percentile for eligible, post-2009 students. We then replicate the propensity score and Mahalanobis matching procedures, limiting treatment and control students to the pre-program cohorts of 2007 and 2008. Table 9 reports average matched differences between pseudo-participants and their nearest neighbors in terms of Mahalanobis distance (Column 1) or participation likelihood (Column 2). Of the 14 pseudo-treatment effects listed in the table, one shares the sign and statistical significance of our main results, although actual certificate gains were twice as large as the pseudo estimate under propensity score matching. Generally, Table 9 provides little reason to believe that student and school features that correlate with Knox Achieves participation in 2009-2011 classes are *a priori* determinants of college outcome gaps between Knox County students and their peers throughout the state.

IV.D. Benefit-cost comparison

Student-level participation in Knox Achieves is associated with an increased likelihood of receiving a certificate or associate's degree and 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. 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.[9] 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. Net benefits reviewed below are robust, in sign, to the possibility that certificates are worth as much as associate's degrees.

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.

[9] 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.

Thus, we re-estimate linear and matching models for the highest degree obtained within six years of high school. As with six-year bachelor's degree receipt, we limit these analyses to the 2010 and 2011 graduating cohorts, who we observe for six years following high school. For linear results, reported in the top panel of Table 10, we estimate the effect of individual Knox Achieves participation in a model with school fixed effects, analogous to the specification in Table 3, Column 2. Knox Achieves is associated with an increase of 8.1 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) = 0.081 * (1,875,023 – 1,334,758) = 0.081 * 540,265 = 43,761.

By a similar calculation, the expected per-participant benefit from higher likelihood of certificate attainment is $8,104, 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 $60,986, meaning that the net change in expected earnings for Knox Achieves participants is -$9,120.

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), we calculate a potential cost of $1,119 * 0.55 * 2.5 = $1,538 for each student who signs up for Knox Achieves in the fall of 12th grade.

Therefore, the benefit-cost ratio is -$9,120/1,538 = -5.93 under the preferred, conservative linear specification of attainment effects, or no more than -0.77 at the upper limit of confidence intervals for certificate, associate's, and bachelor attainment. Moving down the top panel of benefit-cost estimates, we find that the net return is 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 11 times the cost to the funder.[10]

Turning to the bottom panel of benefit estimates, however, we also find that results are very sensitive to the size of the decline in bachelor's degree attainment. Matching-based estimates of this decline were smaller than linear estimates (3-4 percentage points less than the counterfactual as opposed to 5-7), but that subjectively small difference translates into a stark reversal of benefit/cost ratios. Rather than projecting a net loss in lifetime earnings, matching-based treatment effect estimates project large net gains in lifetime earnings. These gains measure 12 times the per-participant cost if a certificate is worth half of an associate's degree and almost 6 times the cost when certificates are worth no more than a high school diploma. This is not solely attributable to the matching methodologies, as alternative linear models reported in Tables 3 and 8 also estimated attenuated negative effects on bachelor's degree completion.

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 smaller than we estimate in the preferred, conservative linear model (such as they are in 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 to 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; 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-achieving and lower-income students in general. These participants tend to collect less in last-dollar aid and 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

[10] 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.

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) are omitted by our focus on highest 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 student persistence through college and completion up to six years after high-school graduation. Because this program is open to all Knox County 12th grade students between 2009 and 2011, we rely on linear and matching estimators to identify effects.

Results are consistent across these different approaches. On average, Knox Achieves participants earned 2-3 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. Program participants were 7-9 percentage points more likely to earn a postsecondary certificate or associate's degree, sizable improvements over control means of 2-4 percent, respectively. Although participants were 5-7 percentage points less likely to complete a bachelor's degree, they have higher quarterly earnings and employment in lucrative industries starting four years after high school. Using Oster's (2017) methods for assessing covariate stability, we estimate that the explanatory

importance of selection on unobservables would need to be many times larger than the importance of selection on observables in order for our findings to be driven by unobserved determinants of college outcomes and interest in a program like Knox Achieves. 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), whereas participants with lower *ex ante* persistence in college were actually more likely to complete a bachelor's degree than their non-participating peers.

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., 2015) and 10.7 percentage points for the El Dorado Promise (Swanson and Ritter, 2018). In addition, the increase in any credential is 10.2 percentage points for Kalamazoo Promise (Bartik et al. 2015), well above the 0.8 percentage-points increase for Knox Achieves (Table 3). 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.

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 students who would not be expected to persist in college. Sizable gains in community college completion, however, are accompanied by sizable declines in bachelor's degree attainment, and this obscures expectations about the net change in lifetime earnings that will arise from tuition-free community college. This uncertainty

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 college completion efforts have evolved in parallel to the expansion of the Knox Achieves model from a privately funded program serving one county to a statewide component of broader attainment goals. Notably, a statewide system of transfer articulation agreements between community colleges and four-year universities 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.

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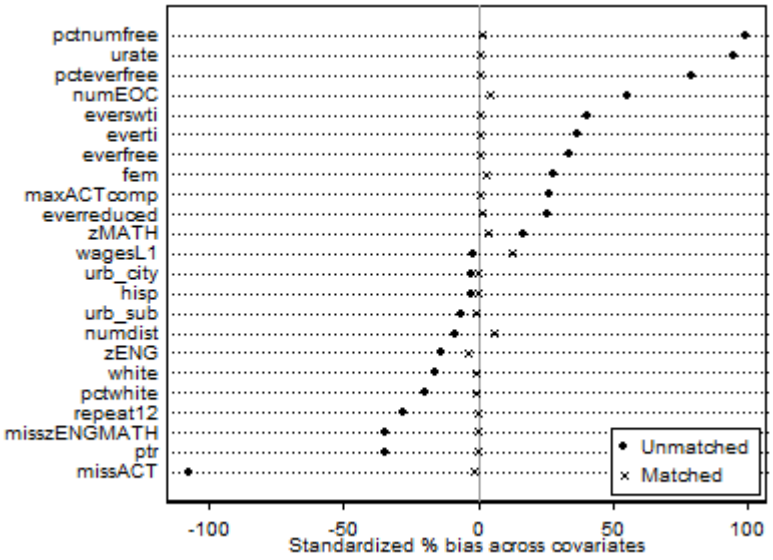
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Table 1. Student summary statistics, by Knox Achieves participation

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
THEC college credits within 2 years of graduation	17.89	23.79	19.62
	(25.07)	(23.61)	(26.26)
THEC college credits within 4 years of graduation	32.43	38.57	38.10
	(46.49)	(42.21)	(50.36)
Ever observed in a THEC 4-year college (0,1)	0.41	0.40	0.42
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 six years (0,1)	0.19	0.17	0.25
In-state earnings 7 years after high school (000s)	6.20	6.43	6.51
	(10.79)	(8.59)	(10.77)
Industrial score 7 years after high school (000s)	11.95	14.56	12.77
	(17.95)	(17.90)	(18.28)
Female (0,1)	0.50	0.61	0.47
Hispanic (0,1)	0.03	0.02	0.02
White, non-Hispanic (0,1)	0.72	0.75	0.81
Free lunch for at least three years, 8th-12th grade (0,1)	0.17	0.31	0.13
Any free lunch, 8th-12th grade (0,1)	0.38	0.48	0.32
Any reduced-price lunch, 8th-12th grade (0,1)	0.12	0.20	0.11
Senior year earnings (000s)	2.13	2.45	2.79
	(3.88)	(3.62)	(5.96)
Junior year earnings (000s)	1.01	1.34	1.43
	(2.52)	(2.62)	(4.22)
Number of counties since 8th grade	1.11	1.08	1.11
	(0.37)	(0.31)	(0.38)
ACT composite (if non-missing)	19.67	19.10	20.88
	(5.26)	(4.47)	(5.50)
Average standardized EOC	0.06	0.18	0.28
	(0.83)	(0.66)	(0.97)
Number of EOC records	2.37	2.67	2.10
	(1.20)	(0.96)	(1.15)
N (students)	307,793	2,109	18,103

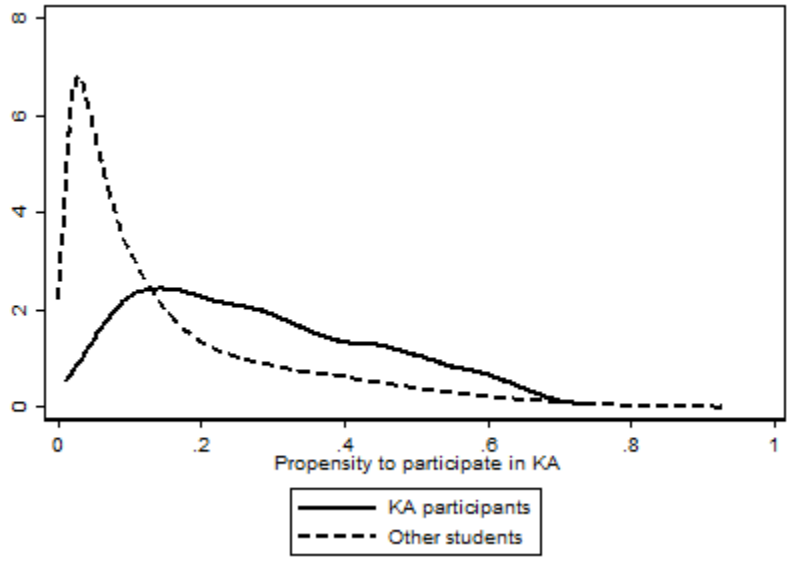
Notes: Standard deviations are in parentheses below continuous variables. The sample includes 12th grade public school students throughout Tennessee, academic years 2006-2007 through 2010-2011, excluding any who enrolled in private or out-of-state institutions. All earnings variables are unconditional: individuals without any reported earnings are assumed to have zero earnings.

Figure 1. 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 2. 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).

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

Measure of treatment	(1) Post-2008 Knox County	(2) Individual KA participation indicator	(3) Post-2008 Knox County	(4) Individual KA participation indicator
School fixed effects	No	No	Yes	Yes
Fitted THEC college credits within 2 years	1.635	1.757	1.514	0.946
	(1.059)	(1.988)	(0.982)	(2.084)
Fitted THEC college credits within 4 years	4.608**	3.870	3.188	1.717
	(2.199)	(4.110)	(2.040)	(4.388)
Fitted binary enrollment in a 4-year THEC institution	0.036	0.027	0.023	0.014
	(0.022)	(0.040)	(0.021)	(0.043)
Fitted certificate attainment within 4 years	0.002***	0.003**	0.003***	0.00109
	(0.001)	(0.001)	(0.001)	(0.002)
Fitted associate's degree attainment within 4 years	-0.001	0.006	0.001	0.003
	(0.002)	(0.004)	(0.002)	(0.004)
Fitted bachelor's degree attainment within six years	0.040**	0.024	0.023	0.007
	(0.016)	(0.030)	(0.014)	(0.031)
Fitted attainment (any) within 150% of normal time	0.039**	0.028	0.026*	0.010
	(0.017)	(0.031)	(0.015)	(0.034)
In-state earnings 7 years after high school	466.37	1,050.33	388.85	1,249.81*
	(307.51)	(783.74)	(287.57)	(701.90)
Students	307,722	307,722	307,722	307,722

Notes: The table lists γ estimates from Equation 1, with and without school fixed effects, where observed outcomes are substituted with fitted predictions from pre-program estimates of Equation 1 (classes of 2007 and 2008). Outcomes are listed at left. Columns 1 and 3 report 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. Bootstrapped standard errors, computed from 200 replications of the model with 10,000 random samples, are in parentheses below each coefficient.

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

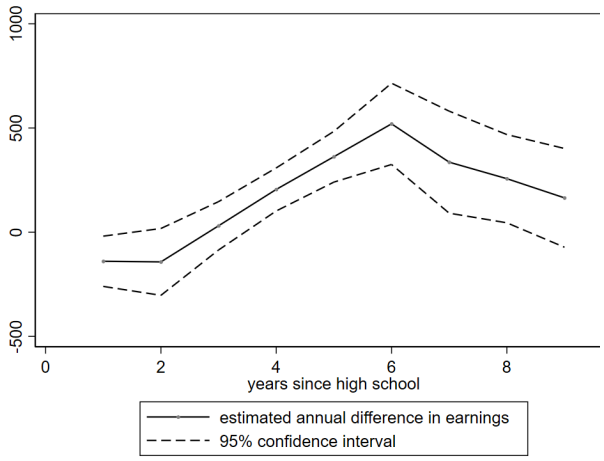
Table 3. Average intent-to-treat and treatment on the treated effects: Knox Achieves and postsecondary outcomes

	(1)	(2)
Measure of treatment	Post-2008 Knox County	Individual KA participation indicator
Trimmed program participants	Top 3.3%	Top 3.3%
School fixed effects	Yes	Yes
THEC college credits within 2 years	1.637***	2.601***
	(0.417)	(0.186)
	17.755	17.846
THEC college credits within 4 years	0.802	-0.323
	(0.619)	(0.330)
	32.218	32.391
Postsecondary certificate attainment within 4 years	0.027***	0.080***
	(0.002)	(0.001)
	0.016	0.017
Postsecondary associate's degree attainment within 4 years	0.010***	0.090***
	(0.001)	(0.002)
	0.036	0.036
Postsecondary bachelor's degree attainment within six years	-0.005	-0.071***
	(0.004)	(0.003)
	0.190	0.192
Any postsecondary attainment within 150% of normal time	0.008*	0.008***
	(0.004)	(0.002)
	0.219	0.221
Treated students	12,342	2,038
All students	307,723	307,723

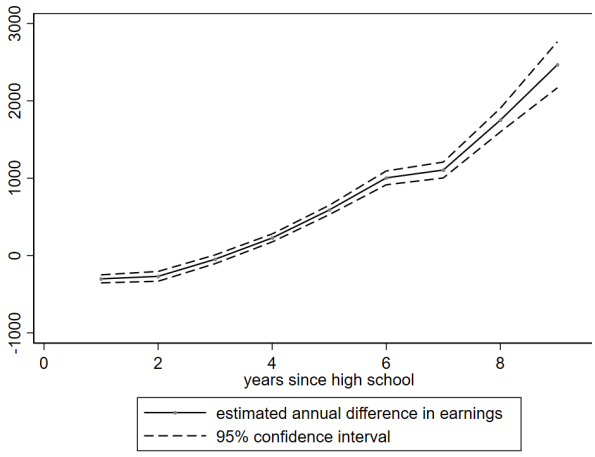
Clustered standard errors are in parentheses. Control means are below the standard errors.
*** significant at 1 percent, ** significant at 5 percent, * significant at 10 percent

Figure 3. Estimated intent-to-treat and treatment-on-the-treated effects of Knox Achieves on in-state earnings, by years since high school graduation

A. Intent-to-treat effect estimates



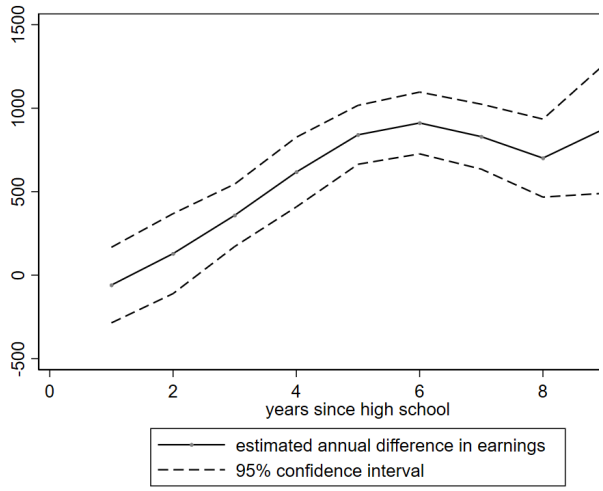
B. Treatment-on-the-treated effect estimates



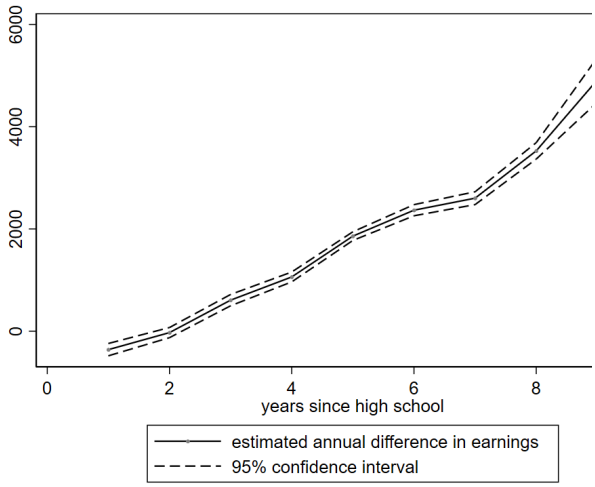
Notes: Each figure traces point estimates (solid lines) and 95% confidence intervals (dashed) from Equation (1) for Knox Achieves availability (panel A) or participation (panel B), by years since high school. The dependent variable in each specification is the level of in-state earnings covered by unemployment insurance, with missing earnings imputed to be zero.

Figure 4. Estimated intent-to-treat and treatment-on-the-treated effects of Knox Achieves on industry score, by years since high school graduation.

A. Intent-to-treat effect estimates



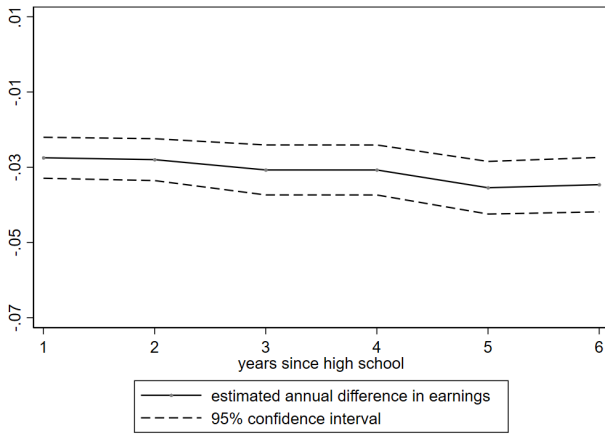
B. Treatment-on-the-treated effect estimates



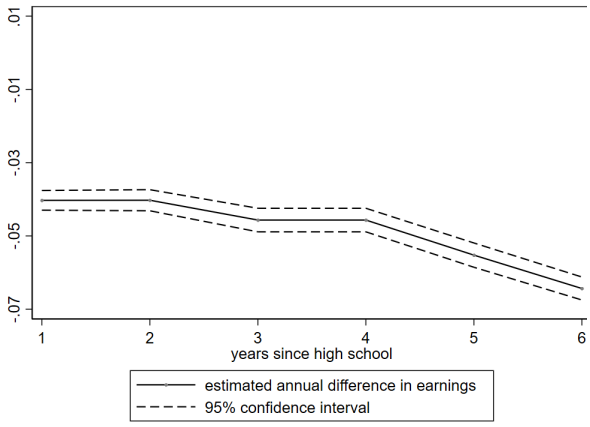
Notes: Each figure traces point estimates (solid lines) and 95% confidence intervals (dashed) from Equation (1) for Knox Achieves availability (panel A) or participation (panel B), by years since high school. The dependent variable in each model is a measure of industry score.

Figure 5. Estimated intent-to-treat and treatment-on-the-treated effects of Knox Achieves on attrition from the sample of workers with in-state earnings, by years since high school graduation.

A. Intent-to-treat effect estimates



B. Treatment-on-the-treated effect estimates



Notes: Each figure traces point estimates (solid lines) and 95% confidence intervals (dashed) from Equation (1) for Knox Achieves availability (panel A) or participation (panel B), by years since high school. The dependent variable in each model is a binary indicator of attrition from the sample of in-state earnings covered by unemployment insurance as of that year.

Table 4: Average intent-to-treat effects: Knox Achieves and postsecondary outcomes, by free lunch status

	(1)	(2)	(3)
Measure of treatment	Post-2008 Knox County	Post-2008 Knox County	Post-2008 Knox County
Ever eligible for free school lunch, 8th-12th grades	No	Yes	Yes
Eligible for free lunch 1-2 years of 8th-12th grade	No	Yes	Yes
Eligible for free school lunch at least 3 years, 8th-12th grades	No	No	Yes
THEC college credits within 2 years	1.887***	2.707***	1.468***
	(0.533)	(0.420)	(0.412)
	22.343	11.148	9.215
THEC college credits within 4 years	0.949	4.223***	1.420***
	(0.846)	(0.554)	(0.435)
	41.272	19.339	15.170
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***	0.015***	-0.011***
	(0.002)	(0.002)	(0.002)
	0.046	0.023	0.014
Postsecondary bachelor's degree attainment within six years	-0.004	0.019***	-0.011***
	(0.006)	(0.003)	(0.004)
	0.254	0.098	0.070
Any postsecondary attainment within 150% of normal time	0.010*	0.042***	0.001
	(0.006)	(0.004)	(0.004)
	0.290	0.118	0.084
Treated students	7,618	1,798	2,926
All students	190,542	64,423	52,758

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

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

Table 5. Average intent-to-treat effects: Knox Achieves and postsecondary outcomes, by achievement and free lunch status

	(1)	(2)	(3)	(4)	(5)	(6)
	Above-median end-of-course achievement			Below-median end-of-course achievement		
Ever eligible for free school lunch, 8th-12th grades	No	Yes	Yes	No	Yes	Yes
Eligible for free lunch 1-2 years of 8th-12th grade	No	Yes	Yes	No	Yes	Yes
Eligible for free school lunch at least 3 years, 8th-12th grades	No	No	Yes	No	No	Yes
THEC college credits within 4 years	-0.342	3.235***	-5.339***	1.727*	4.715***	4.608***
	(1.064)	(0.977)	(1.571)	(0.888)	(0.718)	(0.417)
	55.796	33.425	28.429	20.043	10.990	9.665
Postsecondary certificate attainment within 4 years	0.036***	0.045***	0.015*	0.021***	0.008***	0.006***
	(0.004)	(0.004)	(0.008)	(0.002)	(0.002)	(0.001)
	0.023	0.022	0.017	0.014	0.007	0.006
Postsecondary associate's degree attainment within 4 years	0.013***	0.023***	-0.100***	0.008***	0.005***	0.011***
	(0.002)	(0.005)	(0.009)	(0.002)	(0.002)	(0.001)
	0.056	0.043	0.031	0.033	0.012	0.008
Postsecondary bachelor's degree attainment within six years	-0.011	0.007	-0.027*	0.001	0.030***	0.004**
	(0.008)	(0.008)	(0.015)	(0.006)	(0.004)	(0.002)
	0.361	0.185	0.149	0.099	0.046	0.037
Any postsecondary attainment within 150% of normal time	0.003	0.056***	-0.021	0.011*	0.033***	0.015***
	(0.007)	(0.009)	(0.019)	(0.007)	(0.006)	(0.003)
	0.401	0.219	0.175	0.128	0.058	0.046
Treated students	5,438	832	1,033	2,180	966	1,893
All students	114,050	24,136	15,652	76,492	40,287	37,106

Notes: The table lists γ estimates from Equation 1 ITT estimates of the effect of Knox Achieves availability on college persistence and attainment 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.

Table 6. Average treatment on the treated effects: Knox Achieves and postsecondary outcomes, by achievement and *ex ante* postsecondary persistence

Measure of aptitude	(1)	(2)	(3)	(4)
	Predicted college credits after 4 years		End-of-course achievement	
	Above median	Below median	Above median	Below median
THEC college credits within 2 years	2.499***	1.225***	1.549***	1.619***
	(0.624)	(0.376)	(0.530)	(0.411)
	27.519	8.228	26.793	8.857
THEC college credits within 4 years	1.171	1.933***	0.108	2.460***
	(1.171)	(0.523)	(0.949)	(0.546)
	50.406	14.474	49.508	15.196
Postsecondary certificate attainment within 4 years	0.040***	0.003***	0.037***	0.011***
	(0.003)	(0.001)	(0.003)	(0.001)
	0.024	0.009	0.022	0.011
Postsecondary associate's degree attainment within 4 years	0.016***	-0.003	0.014***	0.004***
	(0.002)	(0.002)	(0.002)	(0.001)
	0.055	0.018	0.051	0.021
Postsecondary bachelor's degree attainment within six years	-0.004	0.009**	-0.009	0.010***
	(0.008)	(0.004)	(0.007)	(0.004)
	0.315	0.068	0.312	0.071
Any postsecondary attainment within 150% of normal time	0.015*	0.007*	0.009	0.014***
	(0.008)	(0.004)	(0.007)	(0.004)
	0.356	0.085	0.349	0.090
Treated students	7,962	4,380	7,303	5,039
All students	153,830	153,893	153,838	153,885

Notes: The table lists γ estimates from Equation 1 ITT 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. Control means are listed below standard errors.

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

Table 7. Robustness of average treatment on the treated effects to additional or fewer controls

Measure of treatment is individual KA participation indicator	(1)	(2)	(3)	(4)
Controls	Cohort fixed effects	Basic	Flexible	Selected features among flexible set
THEC college credits within 2 years	4.597***	2.601***	3.587***	3.057***
	(0.425)	(0.186)	(0.529)	(0.526)
R-squared	<0.001	0.267	0.306	0.283
Oster delta estimate		5.15	8.12	5.68
THEC college credits within 4 years	2.764***	-0.323	1.704*	1.077
	(0.878)	(0.330)	(0.978)	(0.971)
R-squared	<0.001	0.272	0.310	0.289
Oster delta estimate		-0.32	8.34	2.97
Postsecondary certificate attainment within 4 years	0.100***	0.080***	0.075***	0.074***
	(0.002)	(0.001)	(0.003)	(0.003)
R-squared	0.004	0.017	0.034	0.027
Oster delta estimate		5.36	4.76	4.87
Postsecondary associate's degree attainment within 4 years	0.105***	0.090***	0.086***	0.082***
	(0.005)	(0.002)	(0.005)	(0.005)
R-squared	0.002	0.036	0.046	0.038
Oster delta estimate		9.12	7.81	7.92
Postsecondary bachelor's degree attainment within six years	-0.046***	-0.071***	-0.038***	-0.052***
	(0.008)	(0.003)	(0.012)	(0.011)
R-squared	<0.001	0.192	0.206	0.192
Oster delta estimate		-26.6	7.636	459.774
Any attainment in 150% of normal time	-0.036***	-0.008***	-0.027**	-0.030***
	(0.012)	(0.002)	(0.010)	(0.010)
R-squared	<0.001	0.221	0.299	0.273
Oster delta estimate		5.36	4.05	5.88
Treated students	2,038	1,917	1,917	1,917
All students	307,722	300,106	300,106	300,106

Notes: The table lists γ estimates from Equation 1, ATT estimates of the effect of Knox Achieves 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	2.89	***	3.66	***	2.84	***	3.72	***
	(0.67)		(0.75)		(0.68)		(0.75)	
THEC college credits within 4 years	0.53		2.74	**	1.13		2.64	**
	(1.22)		(1.33)		(1.24)		(1.34)	
Postsecondary certificate attainment within 4 years	0.077	***	0.093	***	0.091	***	0.094	***
	(0.009)		(0.008)		(0.008)		(0.008)	
Postsecondary associate's degree attainment within 4 years	0.078	***	0.092	***	0.086	***	0.094	***
	(0.010)		(0.009)		(0.009)		(0.009)	
Postsecondary bachelor's degree attainment within six years[1]	-0.041	***	-0.027		-0.029	*	-0.043	***
	(0.016)		(0.016)		(0.016)		(0.017)	
Any postsecondary credential within 150% of normal time	0.034	*	0.050	***	0.037	**	0.031	
	(0.018)		(0.019)		(0.018)		(0.019)	
Treated students on support	1,110		1,110		1,110		1,110	
All students on support	244,037		241,589		237,084		234,709	

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 propensity 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. [1]Bachelor's degree receipt within six years is observed for classes of 2007-2010.

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

Table 9. Matching balancing test: Pseudo-Knox Achieves participation and postsecondary outcomes

	(1)	(2)	
Control reservoir includes Knox County students	Yes	Yes	
Matching method	Mahalanobis	Propensity score	
THEC college credits within 2 years	-3.886	2.815	
	(2.42)	(2.07)	
THEC college credits within 4 years	-5.970	1.936	
	(4.00)	(3.56)	
Ever enrolled in a THEC 4-year institution	-0.027	0.015	
	(0.044)	(0.043)	
Postsecondary certificate attainment within 4 years	0.023	0.042	***
	(0.017)	(0.015)	
Postsecondary associate's degree attainment within 4 years	-0.004	-0.011	
	(0.020)	(0.021)	
Postsecondary bachelor's degree attainment within six years	-0.042	0.026	
	(0.032)	(0.029)	
Any postsecondary credential within 150% of normal time	-0.049	0.034	
	-0.036	-0.033	
Pseudo treated students on support	265	265	
All students on support	8,140	11,3054	

Notes: The table lists Mahalanobis and propensity score matching results for postsecondary outcomes (average treatment on the treated, or ATT). The sample of East Tennessee 12th graders is limited to the classes of 2007 and 2008, prior to the introduction of Knox Achieves. Pseudo program participation is assigned for Knox County seniors in the top quarter of estimated program participation. We use a nearest-neighbor matching estimator, matching each pseudo participant with replacement to another student with the closest participation propensity (outside of Knox County) or with the smallest gap in the Mahalanobis distance metric. 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.

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

Table 10. Estimated Change in Lifetime Earnings from Knox Achieves Participation

	Expected Change in Lifetime Earnings (in thousands)				Benefit Cost
	Certificate	Associate's	Bachelor's	Total	Ratio
Linear estimates: 6-year highest attainment	0.030	0.081	-0.071		
(Table 3, Column 2 specification)	(0.001)	(0.001)	(0.003)		
Certificate Benefit = 1/2 Associate's	$8,104	$43,761	-$60,986	-$9,120	-5.93
Certificate Benefit = 1/4 Associate's	$4,052	$43,761	-$60,986	-$13,172	-8.56
Certificate Benefit = 1/8 Associate's	$2,026	$43,761	-$60,986	-$15,198	-9.88
Certificate Benefit = 0	$0	$43,761	-$60,986	-$17,224	-11.19
Matching estimates: 6-year highest attainment	0.036	0.091	-0.041		
(Table 8, Column 1 specification)	(0.008)	(0.012)	(0.016)		
Certificate Benefit = 1/2 Associate's	$9,725	$49,164	-$40,329	$18,560	12.06
Certificate Benefit = 1/4 Associate's	$4,862	$49,164	-$40,329	$13,697	8.90
Certificate Benefit = 1/8 Associate's	$2,431	$49,164	-$40,329	$11,266	7.32
Certificate Benefit = 0	$0	$49,164	-$40,329	$8,835	5.74

Notes: The table reports estimates of benefits to program participation in terms of higher lifetime earnings. In the top panel, linear estimates replicate the Table 3, Colum 3 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. In the bottom panel, matching estimates replicate the Mahalanobis model of Table 7, Column 1, for highest certificate or degree attainment within 6 years of high school. Standard errors for Mahalanobis matching are computed according to Abadie and Imbens (2006). Costs of program participation are assumed to be $1,538 in each model, 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. Benefits are Tennessee-specific estimated lifetime earnings returns over a high school degree derived from the 2012-2016 ACS (Blomquist et al., 2014).