Misinterpretation as an Information Friction? Activating School-Based Agricultural Education in Liberia with Parental Engagement

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November 2026

Job Market Paper

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Abstract

Many developing countries have understaffed agricultural extension systems, which slow technology diffusion and, through low productivity, pressure households to keep children out of school. This paper demonstrates an innovative school-based approach that breaks this chain, but only if parent-school linkages are strengthened. In a three-year experiment across 197 Liberian schools, I evaluate school-based agricultural education (SBAE)—a voluntary program training science teachers to integrate inquiry-based learning with student-led school farms and home projects, so that schooling carries an informational return on farming techniques. Whether that return reaches the household depends on how parents respond, so across SBAE schools I cross-randomize two parental engagement treatments, a promotional video and an annual field day, comparing SBAE with and without this combination. With engagement, SBAE improves targeted outcomes: students' households adopt 26–53% more yield-improving farming techniques, dropouts fall 4–5 percentage points per year, and absenteeism falls 28%. It ranks among the most cost-effective programs for technology adoption and school attendance. SBAE trains teachers and students effectively regardless of parental engagement, but without engagement its two diffusion channels—parents' visits to school farms and students' home projects—stay muted. Technology adoption vanishes, educational inputs fall, and parents disconnect: fewer than half visit school farms in three years, and parent–teacher meetings fall 39%. Parents' persistent avoidance of information, plus sharply reversed outcomes under engagement, presents a puzzle: Bayesian updating with a single prior, selective attention, and associative memory each fall short on their own. I propose an integrative explanation: parental engagement shifts parents away from viewing agriculture and education as substitutes.

*Global Poverty Research Lab, Northwestern University. Email: jimmylee@u.northwestern.edu. I thank my advisors Christopher Udry, Dean Karlan, and Lori Beaman for their comments and encouragement. I also thank seminar attendees at Northwestern University, Harvard Center for International Development, Harvard Graduate School of Education, and Oklahoma State University. I acknowledge financial support from the National Science Foundation, the FAO, the Weiss Fund, the Fund for Innovation in Development, Wellspring Foundation, USAID Development Innovation Ventures, the Global Poverty Research Lab and the Buffett Institute at Northwestern University. I thank the Liberian Ministries of Education and Agriculture for sharing administrative data, 4-H Liberia for sharing data on program implementation progress and costs, and Innovations for Poverty Action for excellent data collection work. I thank John Ma, Joshua Tabuena, and Asteris Dougalis for their excellent research assistance. The experiment received IRB approval from Northwestern (STU00211435), IPA (15307) and ACRE (19-11-185), and was pre-registered in the AEA registry (AEARCTR-0006671). A previous version was circulated under the title "Activating School-based Agricultural Extension with Parental Engagement: Experiment Evidence from Liberia". All errors are mine.

1 Introduction

Many developing countries have vastly understaffed agricultural extension systems (Anderson and Feder, 2007), leaving most smallholder farmers without access to professional agronomic advice. As a result, techniques that could raise agricultural productivity and improve livelihoods diffuse slowly. The problem is most acute in sub-Saharan Africa, where ratios often approach one extension officer per 5,000 farm households (Moore, 2017) and agricultural productivity growth has lagged dramatically behind other developing regions since the 1960s (The World Bank, 2008). Without improved techniques to manage their soils, households' yields fall as soils degrade under economic and population pressures (Jayne et al., 2014). Falling yields and food insecurity lead parents to keep children out of school for farm work (Beegle et al., 2006; Edmonds, 2005) and to lower their aspirations for children's education and non-agricultural careers. The resulting lack of human capital undermines both farming households' capacity to try new technologies and learn from observations (Foster and Rosenzweig, 1996) and the supply of educated workers needed to staff extension systems (Juma, 2011), closing a vicious cycle. Many interventions aim to speed the diffusion of agricultural technologies by extending the reach of extension systems (e.g., BenYishay and Mobarak, 2019; Cole and Fernando, 2021). Without a change in households' propensity to invest in children's education, however, such interventions can have limited, or even adverse, effects on schooling.[1] Underlying this propensity is a view, widespread among rural households, that children's schooling and farm work are substitutes.

This paper studies an innovative approach that speeds technology diffusion and reshapes this view at once, by turning schools from impractical, low-return institutions into catalysts for rural development. Specifically, I evaluate a school-based agricultural education (SBAE) program that trains science teachers to integrate inquiry-based instruction with the dissemination of improved farming techniques through student-managed school farms and home projects. At its core, SBAE bundles school attendance with training in new farming techniques and in learning from observation. Because the training is available only through the school, it adds an informational return to schooling and motivates rural households to keep students in school. Building on attendance, SBAE also has the potential to raise the educational return to schooling: it turns the school farm into an open-air laboratory that partly compensates for the lack of textbooks, and it nurtures students' human capital via extracurricular leadership and agribusiness training. In effect, SBAE turns technology adoption and schooling into complements for rural households.[2] Once teachers and students are trained, the curriculum itself drives diffusion through two channels of social learning: school farms serve as demonstration plots for parents and nearby farmers, and students' home projects carry the techniques onto family farms. The latter channel is crucial because farmers are more convinced by trials under familiar conditions (e.g., Munshi, 2004) and by multiple observations (Beaman et al., 2021)—especially in sub-Saharan Africa, where the performance of agricultural techniques varies greatly over small distances (Suri and Udry, 2022).

Despite its promise, SBAE's diffusion channels run through a step outside the school: even successful teacher and student training may fail to translate into changes in household farming practices if parent-school linkages are weak. A large literature documents that parents in developing countries show limited awareness of what and how much their children learn in school (e.g., Banerjee et al., 2010; Dizon-Ross, 2019). These information gaps persist because parent-school engagement is typically limited: schools rarely take initiative to involve parents in school activities, parents with low educational aspirations for their children see little

[1] When labor markets are thin, a more productive farm raises the value of children's time at home. Children of land-rich households work more than children of land-poor households (Bhalotra and Heady, 2003; Dumas, 2007), favorable coffee prices raise child labor and lower attendance in Brazil (Kruger, 2007), and good rainfall years reduce school attendance and long-run human capital in India (Shah and Steinberg, 2017).

[2] Lee and Udry (2026) formalize this complementarity in a target-input model of learning about a new technology's suitability. Under SBAE, the more of a child's time a household devotes to schooling, the more precisely it learns from the school farm's production signals. The informational return to schooling thus carries an option value on the farm, since it raises the probability of future adoption, and SBAE in effect subsidizes information acquisition by delivering it through schooling, whose cost households already bear for its educational return.

value in visiting schools, and poor road infrastructure makes travel to schools costly in time and effort. As a result, SBAE's dual diffusion mechanisms—school farms as demonstration plots and student home farming projects—could fail. Parents who seldom visit the school cannot judge whether the promoted techniques improve yields, or whether a school can teach their children to use them. Skepticism is especially warranted in sub-Saharan Africa, where school gardens have historically served as a source of labor for teachers and as a form of discipline rather than as a setting for learning (Lowe, 1986; FAO, 2010), and such perceptions are common in this study's focus group discussions. As a result, parents unaware of SBAE's educational objectives may treat trained students as more capable farm assistants, raising demands for child labor, and may even reduce educational inputs if they come to see students' futures as bound to the farm. Far from reshaping the view of schooling and farm work as substitutes, SBAE could then entrench it.

This paper therefore asks whether strengthening parent-school linkages is crucial to unlocking SBAE's potential in meeting the dual challenges of technology diffusion and school attendance. I randomly assign an SBAE program called 4-H Liberia across 197 elementary and junior high schools in rural Liberia. The program trains two science or agriculture teachers per school in (i) the yield-improving techniques it promotes, (ii) how to integrate them into science instruction, and (iii) how to run an extracurricular club through which students manage the school farm. Participation is voluntary for both teachers and students. Across program schools, I cross-randomize two light-touch interventions that strengthen parent-school linkages: a one-time promotional video, in which a parent of each sampled student watches a video explaining how SBAE's agricultural and educational components interact, with testimonials from past participants and local authority figures, and an annual farmer field day inviting parents to observe, discuss, and experiment with the promoted techniques on the school farm. Program schools receive the video, the field day, both, or neither. Together, the two interventions account for about 10% of average per-school implementation costs in this study, and about 30% if the video is extended to one parent of every student in each cohort over the three-year trial. The analysis rests on three surveys that mirror the layered randomization. A first follow-up survey of students in the first rainy season captures SBAE's training effects on students before any engagement treatment. Midline and endline surveys of teachers, students, and parents in the second and third rainy seasons capture its effects on the primary outcomes outside school, chiefly agricultural technology adoption and educational inputs, with and without engagement. I track 3,757 households, one for each of about 19 students per school selected at random among students with farming experience, and estimate intent-to-treat effects throughout.

The results deliver one central message: SBAE achieves its goals only when parent-school linkages are strengthened. With both the video and the field day included, the main yield-improving technique is adopted on 18 percentage points more students' parcels and 11 percentage points more parents' parcels, from baseline rates of 29% and 74%. Across the full package of soil management techniques, adoption rises by 53% on students' parcels and 26% on parents' parcels (0.48 and 0.38 standard deviations), large effects relative to village-based extension programs in sub-Saharan Africa, which routinely fail to raise adoption among farmers who are not directly trained (Suri and Udry, 2022). Over two school years, dropouts fall by 4–5 percentage points per year, from 22% and 33%, absenteeism falls by 18% and 28%, and weekly studying hours rise by 7% and 22%. Besides, the SBAE program, augmented with parental engagement treatments, raises students' savings (10 percentage points more students report positive savings, and average annual savings rise by 21%), the share taking agriculture as an elective (18 percentage points), and the share saving for university (6 percentage points). Students shift time away from assisting on family farms while keeping total farming hours constant, contrary to concerns that SBAE would increase child labor. Students' spending and food consumption are unchanged. The SBAE program—augmented with parental engagement treatments—is highly cost-effective against comparable development programs in both agriculture and education. Per $100 spent, it induces at least as many households to adopt new techniques as nearly every other extension program in Africa evaluated by randomized trial. For the increase in total days of attendance, which accounts for both reduced dropouts and reduced absenteeism, it is 1.7 to 2.5 times as cost-effective as a well-cited conditional cash transfer benchmark in Malawi (Baird et al., 2011).

In the arms where parents are not engaged, however, the program fails to achieve either of its goals. Technology adoption does not rise on students' or parents' parcels. Worse, absenteeism rises by 31% and weekly studying hours fall by 20%, relative to control schools. This difference across arms is not due to differences in program participation or training within schools. The first follow-up survey six months into the program, before any engagement treatment, shows that students use and know more about the promoted techniques and hold beliefs about attainable cassava yields consistent with agronomic trials. By the endline, 81% of students have joined the program without engagement, and engagement adds nothing to students' knowledge or beliefs.

What engagement changes, instead, is how households respond to the program: it activates the program's two diffusion channels, which otherwise stay muted. Without engagement, only 44% of parents visit the school farm in three years, the number of visits they make in the second rainy season is no higher than in control schools, and the number of parent-teacher meetings they attend falls by 39%. With engagement, 67% of parents visit, and they report learning five times as many practices from the school. Likewise, the share of students involved in choosing farming methods on their own parcels stays at 23% without engagement, which reflects the absence of home projects, and rises by 15 percentage points with it. The number of techniques students demonstrate to parents rises by 94%, and 18 percentage points more parents report observing improved yields on students' parcels. Parents also update their beliefs: the share expecting students to harvest more than typical adult farmers in the community more than doubles immediately after the video. The randomly assigned video version significantly affects how far these beliefs move. These post-video beliefs in turn strongly predict parents' subsequent visits to school farms, their ability to name field officers, and their attendance at parent-teacher meetings.

Taken together, however, two patterns present a puzzle for standard accounts of belief formation and information acquisition. The first is parents' disconnection from the school: without engagement, parents forgo cheap and readily available information about a program their children have joined—many never even visiting the school farm over three school years, and in fact attending significantly fewer parent-teacher meetings than parents in control schools, whose schools received no program at all. The second is the sharp reversal in the program's effects on educational inputs: a single video screening, with little technical content, turns a 31% increase in absenteeism into an 18–28% decrease and a 20% fall in weekly studying hours into a 7–22% rise, and the reversal persists through the endline two years later.

Consider the standard accounts in turn. Take Bayesian updating first. Parents who are uncertain about the program's value might be expected to investigate a school farm within walking distance, particularly when their own children take part in the program. One reading of their reluctance is that they hold beliefs pessimistic enough to make further investigation unattractive. That reading raises a second question: why does a brief video with little technical content produce so large and persistent a reversal, both in educational inputs and in parents' subsequent information seeking? A further difficulty is that SBAE has positive training effects on teachers and students in all three years and across all arms, so an account resting on an unfavorable signal has to explain why parents were misled systematically and persistently, while the same evidence was available to parents in both arms. A Bayesian explanation remains possible, but it must account jointly for parents' initial reluctance to investigate and their later responsiveness to an intervention that does not itself resolve uncertainty about the promoted techniques.

Behavioral accounts of attention and memory offer further possibilities. Selective attention (Schwartzstein, 2014; Hanna et al., 2014) would hold that parents overlook the program's science instruction, improved techniques, or home projects. Yet the contrast between the two engagement treatments suggests that directing attention to technical features is not enough on its own. The field day exposes parents to demonstrations of the improved techniques on the school farm, and carries more technical content than the video, but leaves dropouts and parents' technology adoption unchanged, whereas the video, which explains how agricultural training and education fit together, changes both. What parents notice therefore seems less important than how they read the program as a whole. Associative memory (Bordalo et al., 2020, 2026) explains why a farm

at a school calls to mind familiar school gardens, but not why parents forgo the inexpensive evidence that would settle the matter.

These patterns motivate an explanation centered on how parents interpret the program, and on how those interpretations govern the value of acquiring further information. The explanation I propose returns to the view at the root of the vicious cycle between stagnant agriculture and low human capital: that schooling and farm work are substitutes. Without engagement, parents interpret SBAE through this default view, reinforced by the common experience of school gardens as drudgery that trains obedient farm assistants. Under this view, a program that trains children in farming raises the relative return to using them as farm labor rather than keeping them in class, which explains why absenteeism rises without engagement while dropouts are unaffected. The alternative view, that the school farm is applied science raising the returns to both schooling and farming, cannot be confirmed by any single observation. Whether it is correct becomes clear only through repeated observations over time, such as visiting the school farm at different points in the season or assigning students a trial plot and watching the results. Gathering such evidence takes time and effort, and when past experience makes parents confident in the default view it promises too little to justify the cost. In a companion theoretical paper (Lee, 2026b) that draws on the neuroscience of cognitive maps (O'Keefe and Dostrovsky, 1971; O'Keefe and Nadel, 1978; Hafting et al., 2005), I formalize this as a curiosity failure: having classified SBAE as a school garden under the costless default, parents assign too little weight to the alternative view for its evidence to be worth gathering. The explanation is integrative rather than a rival to the accounts above, with associative memory supplying the default view, Bayesian updating governing how engagement shifts weight between the two, and attention selective across views rather than across features within one.

According to this explanation, the parental engagement treatments, which operate most strongly through the promotional video, work in two ways beyond supplying facts. First, the video provides surprising evidence that is hard to reconcile with the default view, such as town chiefs' testimony about previous program participants' management skills and transformed livelihoods. Second, by explaining how the agricultural and educational components of 4-H interact, alongside endorsements by government officials and teachers, the video activates the alternative view: that children's farming activities and schooling can be complements. The video does not settle the matter, but it makes that view worth looking into, and parents then visit and learn from school farms, assign plots to students for home projects, and discuss the new techniques within the household. In the companion paper (Lee, 2026b), I derive observable implications that distinguish this account from standard Bayesian and behavioral models.

Related literature. This paper makes four contributions. First, it shows how complementary household interventions can unlock the hidden potential of school-based development programs. A large literature finds that informing parents about returns to education (Jensen, 2010), children's academic performance (Dizon-Ross, 2019), and study effort (Bergman, 2021) improves educational investments, and that strengthening parent-school linkages within the existing school system improves student outcomes.[3] In both cases the school itself stays as it is. I strengthen parent-school linkages at the same time as a new school program is introduced. Without engagement, households fail to take advantage of the information and opportunities the program makes available. More broadly, evaluations that omit complementary household interventions may underestimate the potential of otherwise effective programs. While the meta-analysis of Angrist and Meager (2023) shows that the treatment effects of education programs depend crucially on how they are implemented, I show that even a well-implemented school program may fail when the household responses needed to realize its benefits do not materialize. Because demonstrated success often determines whether programs receive support for further evaluation and scaling, overlooking such complementarities may prematurely discourage

[3]Interventions of this kind include informing parents about school oversight committees in India (Banerjee et al., 2010), inviting parents to meetings with school staff in France (Avvisati et al., 2014), strengthening school committees in Indonesia (Pradhan et al., 2014), and sending Pakistani parents report cards with their child's and their school's test scores (Andrabi et al., 2017). Di Maro et al. (2024) cross-randomize engagement with parents at home and at school in Angola.

investment in promising approaches and distort the accumulated evidence on program effectiveness.

Second, this paper provides proof of concept for an integrated approach to rural development that simultaneously promotes agricultural technology diffusion and school attendance. Aiming to overcome the shortfall in extension coverage, a large literature studies ways to improve the reach of agricultural extension among adult farmers.[4] A separate, nascent literature examines the transmission of school-taught agricultural knowledge to parents, through computer-based instruction in Peru and Uganda (Nakasone and Torero, 2016; Fernández et al., 2024) and junior farmer field schools in Uganda (Bonan and Pagani, 2018). These studies establish the promise of intergenerational knowledge transmission but leave open whether schools can function as cost-effective hubs for agricultural extension. This paper establishes this promise in two ways. First, I estimate intent-to-treat effects for all sampled schools and students, accounting for the high teacher turnover and student dropout that are typical in developing countries. Second, SBAE integrates agricultural extension into the existing science curriculum and extracurricular clubs, through inquiry-based instruction and farm work, so that it can run where literacy is low and computer and internet infrastructure is absent.

Third, this paper contributes a new perspective to the literature on agricultural work and human capital formation by showing how agricultural education can reconcile three objectives often in tension: developing students' agribusiness skills without diverting them from long-term educational aspirations or increasing child labor. Most students in rural Africa are expected to enter agriculture (Filmer and Fox, 2014), yet many view farming as low-return, low-status work (Yeboah, 2018; Blimpo and Pugatch, 2021). Agricultural education therefore raises two concerns: training students in farming may make them more productive child labor,[5] while those aspiring to non-agricultural careers may see little value in it. SBAE addresses both through (i) integrating generalizable skills, via science, agribusiness, and leadership training, into agricultural training; and (ii) voluntary participation and empowerment through student-led school farms and home projects. This paper shows that these concerns are well founded and that the competing objectives can nonetheless be reconciled, but only with parental engagement.

Finally, this paper contributes to the empirical literature on information frictions by documenting a puzzle in information acquisition. People often fail to use information that is readily available (Handel, 2013; Bhargava et al., 2017; Handel and Schwartzstein, 2018; Dizon-Ross, 2019), sometimes avoid information that is free and useful (Golman et al., 2017), and overlook features of their own experience (Hanna et al., 2014). A parallel literature explains choices by what comes to mind, where a cue determines which representation of a situation is retrieved (Gennaioli and Shleifer, 2010; Bordalo et al., 2020, 2023, 2025; Enke et al., 2024; Bordalo et al., 2026), while coarse thinking groups situations into categories and carries the content of information from one to another (Mullainathan et al., 2008). In both, classification feeds directly into choice. The evidence here suggests that classification also governs whether people gather information at all. Parents who read a school farm as a familiar school garden never go to look, and a single cue carrying no technical content changes what they gather for two years afterwards.

Organization. Section 2 describes the study setting and the SBAE program. Section 3 explains the experimental design. Section 4 presents the effects of SBAE with and without parental engagement. Section 5 examines mechanisms. Section 6 discusses how parents read the program. Section 7 concludes.

[4] These include using incentives for selected farmers to communicate techniques to their peers (BenYishay and Mobarak, 2019), social network data to choose those farmers (Beaman et al., 2021), mobile-phone advice (Aker, 2011; Fafchamps and Minten, 2012; Cole and Fernando, 2021; Fabregas et al., 2023), and private input suppliers as agents of knowledge transmission (Dar et al., 2024).

[5] A large literature documents this tradeoff, between children's immediate value in agricultural production and investment in their schooling. See Ravallion and Wodon (2000), Bhalotra and Heady (2003), Beegle et al. (2006), De Janvry et al. (2006), Dumas (2007), Kruger (2007), Edmonds and Schady (2012), and Shah and Steinberg (2017).

2 Study background

2.1 Agriculture and education in Liberia

This study is conducted in Liberia where 72% of households live in absolute poverty (Benfica et al., 2018). Agriculture is the primary source of livelihood for about 80% of the population (African Development Bank, 2008). Smallholder farmers in this tropical region traditionally employ a fallow system under collective ownership of the land.[6] This system operates smoothly with minimal inputs to the soil — no tillage nor use of fertilizers — if the fallow period is sufficiently long. However, as in many other sub-Saharan African countries, farmers are forced to shorten the fallow period under economic and population pressures, leading to commonly observed soil degradation and declining agricultural output.

Agricultural intensification — increasing output per unit of land by increasing inputs to the soil — is the common response to soil degradation. Managing the shift to agricultural intensification, however, requires farmers to acquire soil management techniques that are fundamentally different from traditional techniques. In Liberia, this progress is hindered by low levels of coverage by extension services (3.4%) and low levels of education — the average household head has four years of schooling. As a result, Liberia has very low levels of yields in major staples even by the standard of sub-Saharan Africa — FAO (2023) data suggests that rice and cassava yields are only 54% and 62% of the regional average.

Besides low agricultural productivity, Liberia also has an education system with lower school attendance than those in most sub-Saharan African nations. Liberia has a net primary enrollment rate of only 44% in 2017, compared to the regional average of about 80% in sub-Saharan Africa (UNESCO Institute for Statistics, 2020). Overage enrollment is particularly serious — over 40% of primary school students are above 12 years old; and about 50% of junior high students are 18-20 years old (Liberian Ministry of Education, 2017). Another reason is the high annual rates of student dropouts, which stand at 10-15% in upper primary and junior high grades.

Other than socioeconomic factors, such as poverty and needs for farm labor, a lack of quality instruction and educational resources are important reasons discouraging school attendance. Only 51% of all teachers are qualified to teach — this drops to 33% in junior high. Lacking the required certificates, unqualified teachers also do not receive in-service teacher training from the government. A lack of essential educational resources, such as textbooks, further worsen teacher instruction. Many students are forced to spend a significant portion of class time on copying from the blackboard. These factors are particularly discouraging for rural students who anticipate an agricultural career, as the way knowledge is taught hardly feels relevant to them.

2.2 School-based agricultural education as an integrative model

School-based agricultural education (SBAE) has a century-old history in rural America, dating back to the Smith-Hughes Act of 1917. At its core is an integrative model that blends the promotion of modern farming practices with student-centered learning experiences. According to Croom (2008), this model has three interrelated components. Through formal instruction, students learn the scientific basis of modern farming practices through lectures and demonstration. But more important are the other two components that ensure personalized learning experiences for rural students. Through participation in extra-curricular agricultural clubs, students develop their sense of belonging in a national network, meet mentors and role models, and gain leadership experiences and recognition in public services and competitions. Through supervised agricultural experiences, students can develop home projects tailored to their own pace and needs. Rufus Stimson, an early advocate of the method, argues in particular that home projects allow students to profit from farm work and complement school projects that are subject to overcrowding amongst students (Stimson, 1919).

In the sub-Saharan African context, SBAE is an important new model in the delivery of agricultural

[6] I use the term collective ownership here to refer to communal land tenure or lineage-based land tenure.

extension and rural education.[7] In particular, SBAE should be distinguished from typical school gardens due to its emphasis on student-centered learning experiences. Typical school gardens are directed by teachers without integration with scientific instruction of modern farming practices, home projects, and a national network of agricultural clubs. By contrast, students participate in SBAE voluntarily, make major decisions on school farms (e.g. choice of crops and use of proceeds), and are empowered to make profits from home projects and gain social recognition from clubs. These distinguishing features of SBAE make it particularly suited to tackle intertwined challenges in agricultural extension and school attendance.

2.3 Components of the 4-H Liberia program

This study examines an SBAE program in Liberia that is managed by the local NGO 4-H Liberia in collaboration with the ministries of agriculture and education. Focusing on the RCT period from January 2021 to December 2023, this program implements the three-component model of Section 2.1 mainly through in-service teacher training and regular extension visits by extension officers.

Teacher training is offered twice a year to two teachers per school. These teachers are selected by the participating schools with the requirement that they teach either science or agriculture. The duration of each training workshop is 20 hours that are spread across several days, with roughly equal time covering (i) the integrative SBAE model; and (ii) the promoted yield-improving agricultural technologies. To ensure proper implementation of the SBAE model and diffusion of technologies, teacher training is reinforced by monthly extension visits. During these visits, extension officers monitor progress on school farms, collect information from student participants, and provide lessons on agriculture.

The 4-H Liberia program implements the three-component SBAE model in the following ways. First, formal instruction of agriculture and science is offered through a combination of extension visits and inquiry-based instruction by teachers. Students attend lessons provided by extension officers, while teachers are given instructional ideas that they can adopt during classes. In particular, teachers are given structured lesson plans to illustrate scientific concepts that are associated with promoted farming practices, such as (i) using seed germination tests to illustrate how to conduct a scientific experiment; (ii) using farm site selection to illustrate what a soil profile is; and (iii) using the practice of composting to illustrate the concept of a chemical compound. Besides work on the school farm, teachers are also encouraged to use other inquiry-based methods such as field trips, role plays, and dramas to pique students' interest in scientific knowledge.

Then, extra-curricular 4-H Clubs provide a series of learning experiences. In each school year, every participating school recruits 25-30 club members. These members then participate in, on average, two hours of farm work per week after school. They also meet, on average, on a bi-weekly basis to discuss club affairs. The most important issues are about the choice of crops in a growing season, ways to guard the school farm against thieves and pests, and ways to use the proceeds from farm. By enrolling in the club, students also earn the opportunity to represent their schools in annual national events. The most important event is the national agriculture fair, during which students compete in displaying their knowledge of agriculture to judges and share stories of successes in applying modern farming practices.

Lastly, the program aims to amplify the diffusion of agricultural technologies to rural communities through (i) using the school farm as a demonstration plot; and (ii) encouraging students to start home projects. The school farm is instructed to be open to visitors, with posters encouraging learning of promoted techniques by parents and farmers. To enable students to manage their own farms and make profits from the adoption of promoted techniques, extension officers provide lessons on agribusiness, including farm management and record keeping practices. Teachers are also encouraged to supervise students through home and farm visits.

[7] As in the case of agricultural education in early US history, separate provisions of agricultural training and agricultural youth clubs can be found in some sub-Saharan African countries — for example, agricultural youth clubs affiliated with the international 4-H network can be found in 15 African countries. But the integrative SBAE model has only been introduced by the US-based NGO AgriCorps to Liberia and Ghana since the 2010s.

2.4 Promoted agricultural technologies

Agriculture is an inherently complex activity that requires flexible practices with respect to local environments. The 4-H Liberia program thus provides a wide range of techniques that extension officers and teachers can choose to implement on the school farm. These techniques are grouped under the categories "soil management" (e.g. bed preparation), "crop protection" (e.g. weeding), "improved input use" (e.g. improved seeds or crop varieties), "improved planting practices" (e.g. transplanting), "improved nursery practices", "harvesting practices", and "record keeping practices".

Under the advice of the Liberian Central Agricultural Research Institute, I focus on four soil management techniques that are most widely adopted and expected to improve crop yields, based on agronomic trials and findings from agricultural development programs in Liberia. The four specific techniques are (i) bed preparation methods; (ii) composting; (iii) regular spacing; and (iv) row planting.

These four techniques are promoted to improve agricultural productivity amidst soil degradation in a bush fallow system. Farmers employing the system typically clear land by cutting and burning vegetation. Because of the fertile soils created, farmers do not need extra tillage and instead sow seeds directly into the ground. To reduce the risk of single crop failures and pests, farmers often plant several crops, such as rice and cassava, in proximity. While these practices quickly drain soil nutrients, they are sustainable with traditional fallow periods, which could be as long as 10-15 years. With reduced fallow periods, however, farmers are increasingly unable to cope with agronomic problems such as soil erosion, soil compaction, and waterlogging.

Bed preparation methods, which include mounds or ridges for root crops and raised beds for vegetables, are the main yield-improving technique in this context. These methods help loosen the soil and enhance drainage, thus facilitating root penetration while avoiding waterlogging and topsoil erosion. Other promoted techniques tend to reinforce the effects of beds — with larger yield gains when adopted together. Composting provides a low-cost alternative to chemical fertilizers for improving soil fertility. Row planting and regular crop spacing help optimize the growth of individual plants by avoiding inter-plant competition for nutrients.

Agronomic trials in the tropical humid region in general recommend the promotion of these soil management techniques. In particular, several agronomic trials by the International Institute of Tropical Agriculture (IITA) suggest that the use of mounds and ridges can significantly increase root crop yields — cassava by 31-46% (Odjugo, 2008) and sweet potatoes by 70% (Agbede and Adekiya, 2009). These trials have two important features. First, the yield gains are found under conditions that mimic the traditional cultivation style with minimal soil inputs and random spacing. Second, consistent with anecdotes from program participants, the differences are easily visible, as indicated in the stem height and leaf size within 3 months of planting, and the number and size of tubers per plant at harvest.

These techniques are widely applicable for root crops and vegetables, which are grown by over 80% and 60% of households respectively (LISGIS, 2017). Farmers are also generally aware of these techniques — for example, 80% of control school parents are able to describe mounds or ridges as a way of planting root crops and 74% apply bed preparation methods to some parts of their farms in the endline survey.

However, a mixture of risks and increased labor can deter adoption. Returns to these techniques are heterogeneous across growing conditions. Unsure about the benefits, farmers might not incur the additional labor for bed preparation — in the appendix to Section 4.4, I estimate that the labor takes about 150 hours per hectare in a season. In addition, while these techniques are particularly beneficial for root crops, farmers might be reluctant to change their practices due to the important role root crops play in maintaining subsistence. For example, cassava tubers can be stored underground for up to 24 months while its leaves are consumed. One drawback of using bed preparation methods, which loosen the soil, is that farmers might be forced to harvest all produce together at once.

Because of these concerns, farmers seldom apply these techniques at a large scale and rarely apply all techniques together. For example, farmers commonly construct mounds opportunistically (e.g. where ashes are concentrated or where soils are depleted) and plant multiple cassava stakes, along with other crops, in and

along the edges of each mound — minimizing labor and insuring against sprouting failures while missing the benefits from consistent spacing. The proportion of control school parents who adopt bed preparation jointly with one of the other techniques is only 34% in the endline survey. Nor do farmers drastically modify traditional cultivation practices (e.g. intercropping rice with root crops at close distances and planting a large number of crops per parcel) that help maintain subsistence and optimize overall production rather than single crop yields — only 50% of parents use beds while deviating from these traditional practices. These limitations in full-scale adoption, together with a lack of market access, substantially lower the total benefits that farmers can tap from these yield-improving techniques.

While technical training (e.g. management of weeds and pests under new ways of planting) is involved, in this context extension serves mainly to encourage agricultural intensification by demonstrating the possible extent of yield gains. In particular, school farms bear the risks that farmers cannot afford when a bundle of promoted techniques are applied together. By the same token, small-scale projects undertaken by students, who have less obligations to feed the family, can help farmers learn about the returns to a systemic shift to promoted techniques under familiar growing conditions.

The actual yields could, of course, differ from those in agronomic trials.[8] I nonetheless anticipate a net benefit from adoption for the average targeted farmer. In the appendix to Section 4.4, assuming only half of the yield gains from trials — under the traditional cultivation environment — and accounting for increased labor costs, I estimate a $65 increase in net production value from using beds on a quarter of the cultivated area in one season — roughly 13% of a typical farmer's annual income. This measure omits changes at the intensive margin — the joint adoption of bed preparation with other techniques and under deviations from subsistence practices. Given the lack of trial estimates on the magnitude of yield gains under joint adoption, I maintain an agnostic view of its net effects on welfare but track changes in Section 4.2.1, noting its associations with increases in farm sales and agricultural intensification.

3 Experimental design

3.1 Sampling and randomization

Sampling frame. The study takes place in five major food-producing counties of Liberia: Bong, Lofa, Nimba, Gbarpolu, and Margibi. Of the 1,794 junior high schools in these counties, 304 met two eligibility criteria verified by field inspection: land and a water source for a school farm.[9] Eligible schools located within two kilometers of one another were grouped into 206 geographical clusters, so that schools in different clusters are at least two kilometers apart, which limits spillovers between SBAE and control schools. From this frame I randomly drew 197 schools (155 clusters) as the study sample; the program's budget allowed 100 SBAE schools.

First stage: SBAE. Randomization was at the cluster level. Clusters were matched into pairs on extension-officer region and average school enrollment in 2015/16 (one group is a triplet), and within each pair one cluster was assigned to SBAE and the other to control. This yielded 100 SBAE schools in 78 clusters and 97 control schools in 77 clusters. All schools assigned to SBAE accepted the program. Figure 1 summarizes

[8] Suri (2011) provides evidence in Kenya that an agricultural technology that offers large average returns in a population can nonetheless have much lower returns for non-adopters. Focusing on common farming techniques promoted in agricultural intensification, Udry (2024) discusses recent evidence on the drastic difference in yields between agronomic trials and general population in Northern Ghana.

[9] Schools were first screened for a functional parent-teacher association and a water source using the national Water, Sanitation, and Hygiene (WASH) dataset (447 schools), then inspected in the field (304 schools). Online Appendix Table OA1 compares sampled schools with other schools in the five counties; eligible schools are larger and have lower student-teacher ratios than the county average.

the sampling and the two layers of randomization, Figure 2 maps the schools, and Appendix Figure A1 traces participant flow from allocation to analysis.

Second stage: parental engagement. Within SBAE schools, the two parental engagement treatments were randomized at the school level in two separate draws. Each draw covered only the schools eligible for that treatment, and each was stratified by district: within every district, the eligible schools were assigned at random. The two draws were independent of one another, so a school's assignment to one treatment is unrelated by design to its assignment to the other. The two eligibility criteria differ, so the eligible sets overlap only in part, and ineligibility is not random in either case. Section 4.1 therefore conditions on both eligibility indicators. Online Appendix Figure OA2 shows the full assignment tree.

- *Promotional video.* Among the 83 SBAE schools that are not faith-based, 50 were assigned at random within district to host promotional videos for every sampled parent during the first rainy season of 2021. The 17 faith-based schools were excluded because their parents live far from the school and could not be reached at reasonable cost.[10]
- *Annual farmer field day (FFD).* Among the 85 SBAE schools that had established a school farm by August 2021, 44 were assigned at random within district to host a field day in September 2021 and September 2022.

3.2 Treatments and implementation

SBAE. SBAE schools receive bi-annual training of two teachers per school on the integrative SBAE model and the promoted techniques, and monthly visits from extension officers (Section 2.3). Teachers and officers then deliver the three components: agriculture and science instruction (lessons during extension visits and inquiry-based instruction in class), extracurricular activities (weekly farm work, bi-weekly club meetings, annual national events), and technology diffusion through the school demonstration farm and student home projects.[11]

Promotional video. The video is inspirational rather than technical. About six months into the program, during the first student follow-up survey, enumerators invited one parent per sampled student to a 20- to 30-minute screening held outside the school. In groups of four to five, parents watched a video that explains how SBAE integrates inquiry-based science instruction, school farms, extracurricular clubs, and student home projects, and answered survey questions before and after. Half of the parents, randomly selected, watched a version that adds testimonials from past participants, town chiefs, extension officers, teachers, and parents ("the cassava I got was big, big"; "I paid my own school fees"). The video mentions no specific farming technique, so any effect on household farming practices must operate through parents' interactions with students and the program. Both versions raise parents' beliefs about students' farm management abilities immediately after viewing, and the version with testimonials raises them significantly more. These beliefs remain elevated at midline and endline. This paper pools the two versions, and the companion paper (Lee, 2026a) studies them separately. Online Appendix C describes the videos and the immediate belief responses.

[10] Faith-based schools cluster geographically, and by chance SBAE received more multi-school clusters than control, so the share of faith-based schools is higher in SBAE (17 of 100) than in control schools (10 of 97). More schools were assigned to the video arm than to its complement because the companion paper (Lee, 2026a) required a larger sample of parents who watched the video.

[11] Implementation was far from perfect in the first school year, which COVID-19 school closures shortened to eight months, from January to August 2021; this matters for interpreting intent-to-treat effects. By the end of the first rainy season, 70 of the 100 SBAE schools had started a school farm; by August 2021, 85 had. The common reasons for delay were teacher turnover, teachers' non-compliance, and damage to farms from grazing animals and theft. These problems were resolved by the start of the second school year (2021/22).

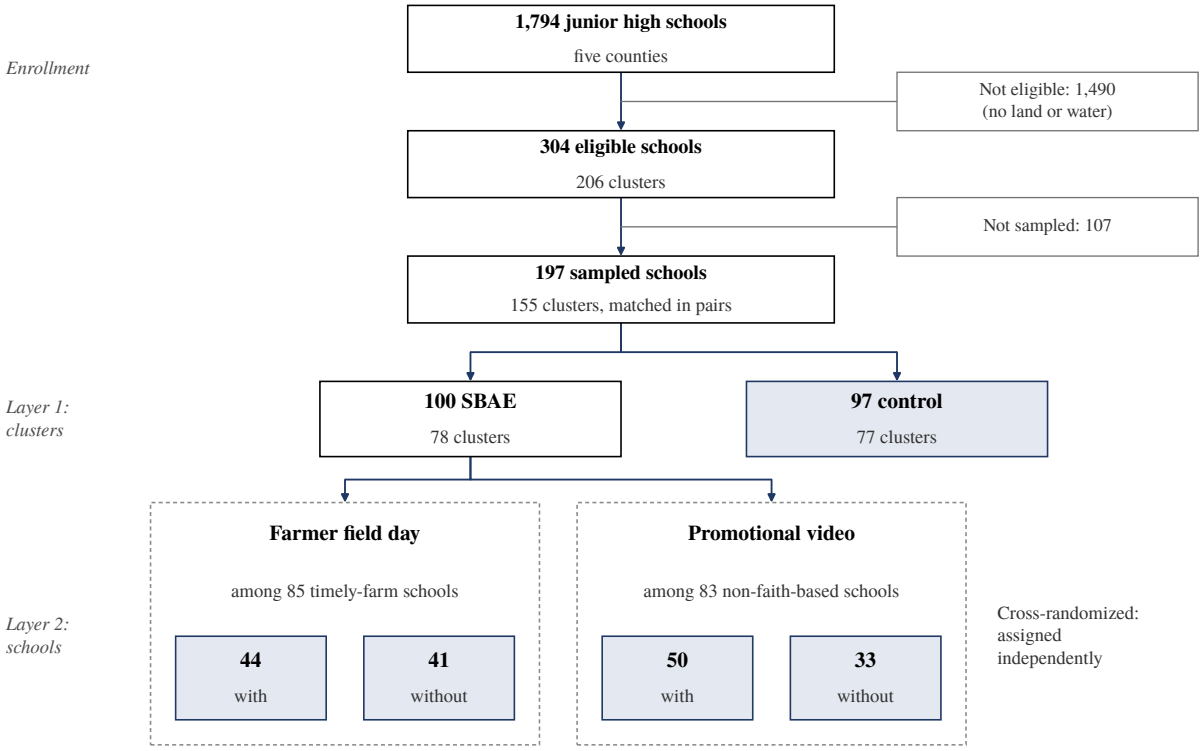


FIGURE 1. EXPERIMENTAL DESIGN OF THE STUDY

Notes: This figure summarizes sampling and the two layers of randomization. Of the 1,794 junior high schools in the five study counties, 304 met the eligibility criteria (land and a water source for a school farm) and were grouped into 206 geographical clusters; 197 schools in 155 clusters were drawn at random and matched into pairs on extension-officer region and enrollment (one triplet). In the first layer, within each pair, one cluster was assigned to SBAE (100 schools, 78 clusters) and the other to control (97 schools, 77 clusters). In the second layer, the two parental engagement treatments were assigned independently at the school level, stratified by district: an annual farmer field day among the 85 SBAE schools with a school farm by August 2021, and a program promotional video among the 83 SBAE schools that are not faith-based. Shaded boxes are the treatment cells used in estimation. Online Appendix Figure OA2 shows the full assignment tree by school type and farm status, and Appendix Figure A1 reports participant flow.

Annual farmer field day. The field day is a training intervention focused on one program component: the school farm as a demonstration plot. Each September of the first two program years, extension officers harvested part of the root crops to show the gains from bed preparation and explained the promoted techniques. Town chiefs were asked to select 25 to 30 farming-group leaders per school to attend alongside parents; each event lasted about six hours. Attendance was not recorded, but Section 5 shows that the field day raises the share of parents who have observed a harvest on the school farm and improves their beliefs about attainable cassava yields.

The two treatments thus target distinct gaps. The video addresses how parents understand the program and the value of students' learning under it; the field day transfers technical knowledge that parents can apply while keeping students as farm assistants. The companion paper shows that the field day alone leads parents to use students as assistants on subsistence parcels rather than as managers of sales-oriented parcels.

3.3 Timeline and data

The program ran from January 2021, the delayed start of the 2020/21 school year, to December 2023, covering three school years and three rainy seasons (Figure 3). Each year a survey round took place in the middle of

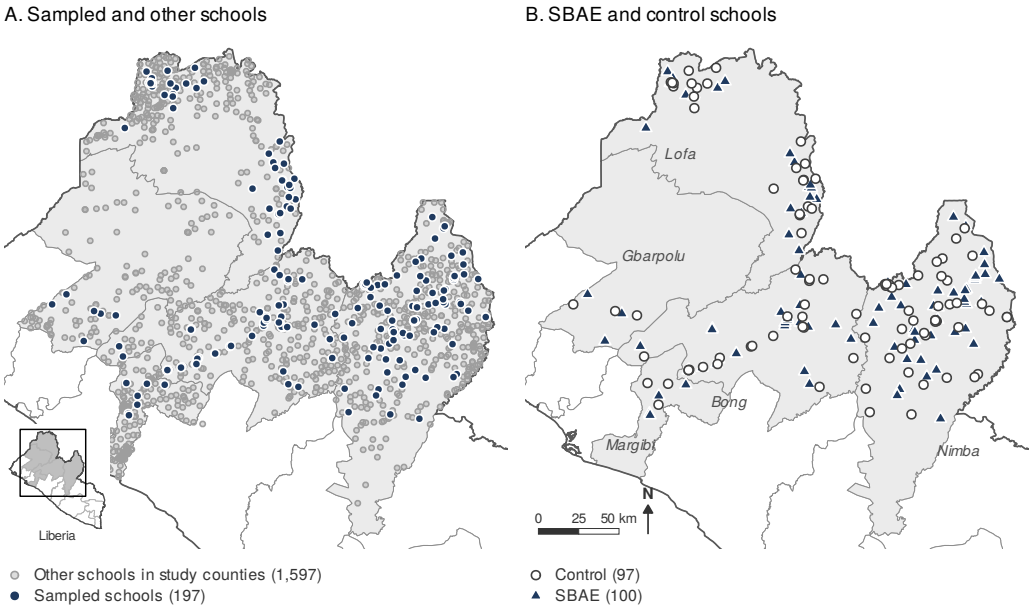


FIGURE 2. GEOGRAPHICAL DISTRIBUTION OF SAMPLED SCHOOLS

Notes: Panel A shows the 197 sampled junior high schools and the 1,597 other schools in the five study counties (Bong, Gbarpolu, Lofa, Margibi, and Nimba), based on Ministry of Education school records. Panel B shows the 100 SBAE and 97 control schools. Study counties are shaded; the inset locates the study area within Liberia. County boundaries are from OCHA (2019).

the rainy season, which coincides roughly with the end of the school year and with land preparation, when adoption of soil management techniques can be observed. The first follow-up survey (2021) captures SBAE's training effects on students before the engagement treatments took effect; the midline (2022) and endline (2023) surveys measure the primary outcomes outside school. Table 1 summarizes the samples by round.

Students. The program recruits students in upper primary and junior high grades. The sample is drawn from grades 4, 5, 7, and 8, excluding grades 6 and 9, whose students leave the school at the end of the year. Within each school, enumerators screened students in these grades during 2020/21 and selected about 19 students who farmed outside school and whose parents farmed, prioritizing students with prior farming and cooperative-group (kuu) experience, who a pilot showed were more likely to participate in SBAE.[12] The resulting 3,757 students, one per household, are 30 percent of students in the targeted grades and closely resemble all eligible students: 99.4 versus 95.0 percent had farmed before, and 82.1 versus 77.1 percent had joined a kuu (Panel B of Online Appendix Table OA1).

Parents. For each sampled student, one parent or guardian (henceforth, parent) who planted root crops or vegetables in 2021 was invited; where both parents qualified, the invitee was chosen at random to balance gender. Because of budget constraints, parents were interviewed only at endline, in a random 45 percent of households. In 95 percent of cases the invited parent participated; otherwise another household member did.

Teachers. To measure school-level changes in instruction, all science and agriculture teachers in each school were interviewed at midline (452) and endline (472) as repeated cross-sections; teacher turnover in rural

[12] Enumerators worked down a priority list (farmed and joined a kuu before 2021; joined a kuu; farmed; other eligible students) until reaching the school's target, which was raised in larger schools and lowered in smaller ones. Within priority tiers, selection balanced section (upper primary or junior high) and gender.

TABLE 1—STUDY SAMPLES BY SURVEY ROUND

	Baseline 2020/21	First follow-up 2021	Midline 2022	Endline 2023
Panel A. Schools				
Control schools (clusters)	97 (77)	97 (77)	97 (77)	97 (77)
SBAE schools (clusters)	100 (78)	100 (78)	100 (78)	100 (78)
with promotional video	–	50	50	50
with farmer field day	–	44	44	44
with both	–	20	20	20
Panel B. Students				
Sampled	3,757	–	–	–
Targeted for interview	–	–	3,757	3,757
Panel C. Parents				
Targeted for interview	–	–	–	1,691
Panel D. Teachers				
Interviewed (repeated cross-section)	–	–	452	472

Notes: The first follow-up targeted all sampled students in the 50 video schools and a random half of sampled students in the other 147 schools. The endline parent survey targeted a random 45 percent of sampled households, stratified by school. Farm modules were administered to a random subset of interviewed subjects.

Liberia is too high to follow individuals.

Survey content. Student surveys cover schooling, time use, livelihoods, aspirations, beliefs, and a test of knowledge about the promoted techniques; parent surveys cover engagement with the school, beliefs, and support for students' education. A parcel-level farm module, administered to a random subset at midline (students) and endline (students and parents), measures technology adoption on one "student parcel" and, at endline, one "parent parcel," chosen at random with priority to parcels the respondent looks after and to parcels planted with root crops or vegetables.

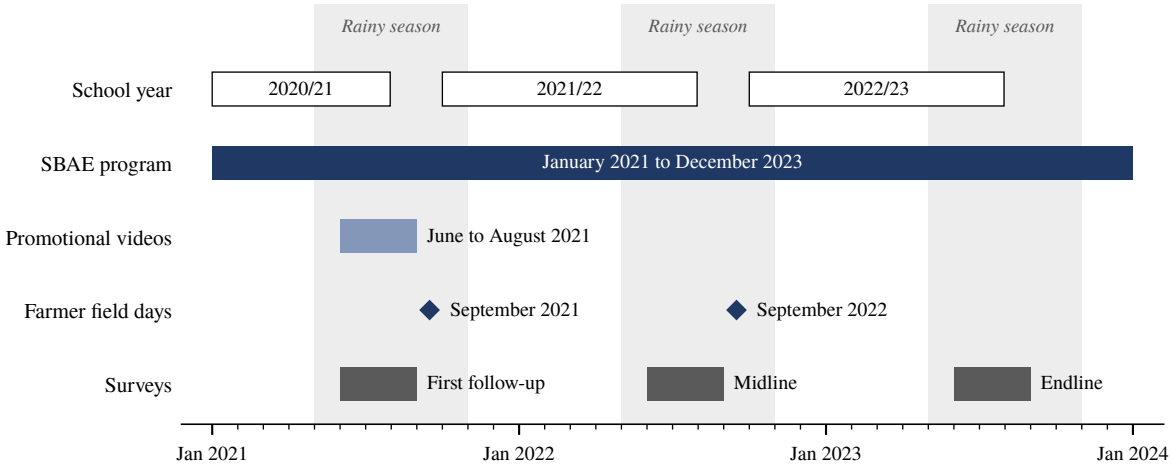


FIGURE 3. TIMELINE OF SBAE PROGRAM AND DATA COLLECTION ACTIVITIES

Notes: Shaded bands mark the rainy seasons (April–October). The 2020/21 school year began in January 2021, three months late, because of COVID-19 school closures. Promotional videos were held for sampled parents in 50 SBAE schools during the first follow-up survey; farmer field days were held in 44 SBAE schools in September 2021 and September 2022. The first follow-up survey covered students; the midline and endline surveys covered teachers, students, and parents.

3.4 Outcomes

Online Appendix D defines all variables. The primary outcomes are pre-specified.

Agricultural technology adoption. I measure the adoption of the promoted soil management techniques on students' parcels (midline and endline) and parents' parcels (endline). For each subject-round there are two primary outcomes: whether bed preparation is used for root crops or vegetables, and the total number of techniques, out of the four outlined in Section 2.4, that are used for root crops or vegetables.

School attendance. I measure students' school attendance at midline and endline by three measures. First, whether students have dropped out of school by the time of the survey, according to school records and to tracking to the household in the case of students who have moved to other schools. Second, absenteeism in the last five school days. Third, the imputed total days of school attendance over 2021/22 and 2022/23.[13]

Students' studying effort. I use the number of hours students spend studying in the week preceding the survey, at midline and endline, as a primary outcome. As supplementary information, I also measure the number of hours students spend farming, inside and outside school, and doing household chores.

Students' livelihoods. I track three dimensions of students' livelihoods. First, their annual incomes, reported retrospectively at endline and disaggregated into farm and non-farm incomes. Second, their annual savings, also reported retrospectively at endline, which are a better measure than incomes in this context because many students farm for their households and may receive transfers instead of incomes. Third, their food consumption and non-food spending. Food consumption is captured inversely by the number of meals students missed in the week preceding the survey, at midline and endline. Non-food spending over the past six months, at midline and endline, is measured in three categories: agricultural inputs, school fees and supplies, and consumption goods such as clothes and footwear, musical instruments, and sports accessories. All variables with monetary values are log-transformed and winsorized at the top and bottom 2.5 percent.

Students' aspirations. I measure students' aspirations in two ways. First, whether students list an agricultural career, including farmer, agronomist, and extension officer, among their top three jobs at midline without being given options. Second, whether students report saving to attend university at endline, as a proxy for their educational aspirations.

Section 5 traces the mechanisms behind these effects with the secondary outcomes below.

Beliefs and experiences about attainable crop yields. Both anecdotes and the agronomic trials discussed in Section 2.4 suggest quick visible signs that yields improve under bed preparation, the main promoted technique, and more so when it is used jointly with the other techniques, especially for root crops such as cassava. Beliefs about the number of attainable cassava tubers per plant therefore provide good proxies for a respondent's exposure to the SBAE program and, through that, for beliefs about the returns to the promoted soil management techniques. To evaluate whether the promoted techniques are in fact beneficial to sampled households, I further ask students and parents in the endline survey whether they have experienced an improvement in yields, in the number and size of tubers, or in the quality of produce over the past two years.

Knowledge about promoted soil management techniques. In each annual survey, I design a test based on the SBAE curriculum to evaluate whether respondents know how, when, and why to use the promoted techniques.

Teachers' pedagogy. Teachers' pedagogy is reported by both students and teachers during midline and endline. I use student reports of teachers' pedagogy unless otherwise stated. I measure teachers' adoption

[13] The imputed measure is based on the student's enrollment status, the rate of absence from school, and a total of 200 school days per school year. A student who has dropped out is counted as having zero school days. A student who switches schools is counted as having the control-school average, which is conservative for the treatment effect because switching is more common in the treatment arms with lower dropout.

of SBAE pedagogy in three ways. First, whether teachers have used agricultural projects or field visits for instruction in the last five school days. Second, the number of scientific concepts, out of six from the science curriculum, that have ever been illustrated with farm work. Third, the number of home visits in the last month and farm visits in the last rainy season. As supplementary information on whether SBAE crowds out other types of teaching effort, I also measure teachers' use of student-centered instruction that is not related to agriculture, such as student presentations and group projects, and whether teachers have provided after-school classes in the last five school days.

Parents' visits to school farms. During the endline survey, I ask parents whether they have ever visited the school farm and the number of times they visited the school farm in the preceding rainy season. I also ask parents whether they have ever worked on the school farm and whether they have observed harvests there.

Students' management of farms. During the midline and endline surveys, I ask students who is involved in choosing the crops and the planting methods on the student parcel. Students can answer that they choose on their own, that they choose after discussing with parents, that they choose what parents would prefer, that parents choose, or that others choose. As primary measures, I define the variables "student chooses crops" and "student chooses methods" to be one if students choose on their own and zero otherwise. As supplementary information, I also ask whether students have ever looked after a farm without guidance from older persons, whether students look after a farm in the current season, the number of parcels they look after, and the number of parcels on which they assist household members.

Technology diffusion within households. During the midline survey, I ask students whether they have ever demonstrated, in four specific ways, the promoted techniques they have applied on the student parcel to household members, and to whom. This enables me to define two measures of demonstration effort that are analogous to the measures of technology adoption: whether students have demonstrated bed preparation to parents, and the number of promoted techniques students have demonstrated to parents.

Parents' support for students' education. During the endline survey, I collect two proxies for parents' support: the number of parent-teacher meetings attended, and whether students have ever been absent from school because of household work. As supplementary information, I also ask whether parents pay students' school fees on time in the current semester, and the amount parents spend on students' agricultural inputs, school fees and supplies, and non-food consumption.

Measures of joint technology adoption. My primary measures of agricultural technology adoption capture the standalone adoption of each promoted technique. As discussed in Section 2.4, there are synergies from the joint adoption of bed preparation with the other techniques. I use two measures to capture the degree to which farmers deepen their agricultural intensification. First, whether bed preparation is applied jointly with at least one of the three other soil management techniques. Second, whether bed preparation is applied jointly with at least one deviation from three traditional subsistence practices: fallowing in the previous rainy season, cultivation on rice fields, and intercropping with rice.

3.5 Balance, baseline sample characteristics, and attrition

Balance. Online Appendix Table OA2 shows that the baseline characteristics of sampled schools, students, and parents are balanced across treatment arms at baseline, that is, at the beginning of the 2020/21 school year. Mirroring the main regressions in Section 4.1, I regress each baseline characteristic on an indicator of SBAE, an interaction between SBAE and the promotional video, and an interaction between SBAE and the annual farmer field day, with pair-of-clusters fixed effects and standard errors clustered at the geographical-cluster level. None of the F-tests of the treatment coefficients across baseline characteristics is significant at the 10 percent level.

Panel A focuses on school characteristics. Schools are balanced in enrollment, the number of teachers, the student-teacher ratio, the number of classrooms, and the number of students sampled. Importantly, schools are also balanced in the variables that could plausibly explain the success of a school farm, namely whether a water source is available nearby and whether breakfasts or lunches are provided. In addition, schools are balanced in school management: the number of visits by government district education officers, school ownership (public, private, or faith-based), whether an enrollment list is kept, and the numbers of parent-teacher association meetings and school management committee meetings.

Panel B focuses on the characteristics of sampled students. Students are balanced in the characteristics used for stratified sampling: they are on average 15.7 years old and in grade 5.7, and 52 percent are male. They are also balanced in years of farming experience, which average 7.9.

Panel C focuses on the characteristics of sampled parents. Because parents were first interviewed at endline, the panel reports characteristics that are time-invariant or pre-determined. As with students, parents are balanced in demographics: they are on average 43.2 years old, 47 percent are male, 74 percent are parents rather than other guardians, and 63 percent are household heads. That parents were not surveyed in the first round has no substantive effect on the experiment. Of the parents who ultimately attended surveys, 98 percent are the ones invited on the basis of student reports, and every sampled parent farms. As is typical in rural Liberia, only 59 percent of parents can read and write English, with 54 percent having completed elementary school and 39 percent junior high school.

Attrition. Of the 3,757 sampled students, 2,520 were interviewed in the first follow-up, 2,425 at midline, and 1,970 at endline; of the 1,691 parents targeted at endline, 1,488 were interviewed. Student attrition is high: 35 percent at midline and 48 percent at endline (Appendix Table A1, Panel A). Panel B shows that it is driven by dropouts (18 and 24 percent) and by transfers to other schools (16 and 21 percent). Most transfers are mechanical. Students in the sampled grades reach the end of a school section and move on to junior or senior high, and some move to schools closer to urban areas. Parent attrition is far lower, at 12 percent, and reflects travel (4.6 percent) and relocation (4.3 percent) rather than exit from schooling.

Attrition is also imbalanced across arms. Neither SBAE on its own nor the farmer field day changes student attrition relative to control schools. The promotional video lowers it by 7.3 percentage points at midline, from 36 percent, and by 9.2 percentage points at endline, from 48 percent. Panel C shows that this difference is accounted for entirely by fewer dropouts and transfers. Among parents, SBAE raises attrition by 4.2 percentage points and the field day lowers it by 4.0 points, while the promotional video has no significant effect.

Online Appendix Table OA3 asks whether attrition is selective on baseline characteristics and whether that selection differs across arms. Students are selected on age and grade, but not on gender or years of farming. One additional year of age raises the probability of attrition by 2.6 percentage points and one additional grade raises it by 2.0 points, so attritors are on average 0.21 standard deviations older and 0.12 standard deviations higher in grade. This is what mechanical progression implies: students in the upper sampled grades are closest to the point of moving to another school section. Parents are selected on age and on whether the respondent is a parent rather than another guardian. One additional year of age lowers attrition by 0.23 percentage points, and parents are 4.3 points less likely to attrit than other guardians, leaving attritors 0.17 standard deviations younger and 0.18 standard deviations less likely to be parents. In both panels, Wald tests on the interactions of the treatment indicators with baseline characteristics cannot reject that selection operates in the same way across arms.

This pattern shapes how the estimates should be read. Because students and parents are selected into the later samples in the same way in every arm, it is the differential attrition rate, not selection itself, that threatens comparability between groups. I therefore report Lee (2009) lower and upper bounds alongside every main estimate, which give the worst and best cases consistent with the observed imbalance. Three further considerations support the estimates. First, dropout is an outcome of interest in this study rather than

only a nuisance, and parent attrition is a quarter of student attrition, so the effects on parents' technology adoption rest on a sample close to the one drawn at baseline. Second, selection among students runs mainly through grade progression, so effects on school-specific outcomes such as absenteeism are estimated on the students who remain enrolled and could benefit from the program. Third, the main effects are consistent across the three survey rounds (Sections 5.1.2 and 5.3), and the Online Appendix shows that they are similar for upper-grade and lower-grade students.

4 Experimental results

4.1 Empirical specification

I analyze SBAE's impact on the primary outcomes: agricultural technology adoption, school attendance, students' livelihoods, and students' aspirations. I estimate intent-to-treat (ITT) effects from

$$\begin{aligned} Y_{hscp} = \alpha + \beta_1 \,\text{SBAE}_p + \beta_2 \,\text{SBAE}_p \times \text{FFD}_s + \beta_3 \,\text{SBAE}_p \times \text{Video}_s \\ + \lambda \,\text{Faith-based}_s + \mu \,\text{SBAE}_p \times \text{Late farm}_s + \gamma_p + \varepsilon_{hscp}, \end{aligned} \tag{1}$$

where Y_{hscp} is the outcome for household h in school s, geographical cluster c, and randomization pair p; SBAE_p indicates that pair p's treated cluster contains school s; FFD_s and Video_s indicate assignment to the farmer field day and the promotional video; Faith-based_s indicates a faith-based school, which was ineligible for the video; Late farm_s indicates an SBAE school that had not established its farm by August 2021 and was therefore ineligible for the field day; and γ_p are randomization-pair fixed effects. The two eligibility indicators absorb the non-random exclusions described in Section 3.1, so that β_1 is the effect of SBAE alone in schools that were eligible for both engagement treatments but received neither, and β_2 and β_3 are identified from random assignment among eligible schools. Standard errors are clustered at the geographical-cluster level, the highest level at which assignment took place.

To maximize statistical power, (1) is what Muralidharan et al. (2025) call the "short model" in a factorial design. β_3 and β_2 give the marginal effects of the promotional video and the annual field day in a sample in which (roughly) half the households are offered the other treatment. The design is underpowered to detect interaction effects. Section 4.3 reports these marginal effects. For the primary outcomes discussed below, the marginal effect of at least one engagement treatment is statistically significant at conventional levels, except for dropouts at midline, positive savings at endline, and naming an agricultural job among the top three at midline, where the combination is significant but neither marginal effect is. In the Online Appendix, I show that the main point estimates are similar when using the "long model" that controls for an interaction term between the two engagement treatments. Following Kaur et al. (2025), I also show in the Online Appendix that the effects of the promotional video (field day) are qualitatively similar in the sub-samples with and without the field day (promotional video).

4.2 SBAE with and without parental engagement

Figures 4 to 8 contrast SBAE with and without parental engagement. For each primary outcome, they plot two estimates from (1): the pure SBAE effect ("without engagement", β_1) and the effect of SBAE augmented with both the promotional video and the annual farmer field day ("with engagement", $\beta_1 + \beta_2 + \beta_3$), each with its 95% confidence interval and Lee bounds. Full regression estimates—including the overall SBAE effect that pools all SBAE schools and the "SBAE + FFD" and "SBAE + Video" combinations—are reported in Online Appendix Tables OA4 to OA10.

4.2.1 Agricultural technology adoption and agricultural intensification

We begin by presenting the results on households' technology adoption in Figure 4, with full estimates in Online Appendix Table OA4.

Figure 4 shows that parental engagement transforms SBAE's effects on technology adoption. Without parental engagement, the effects on the student parcel are small and statistically insignificant at both midline and endline, and on the parent parcel SBAE raises only the number of techniques used. With both forms of parental engagement, SBAE raises students' use of bed preparation by 15.0 percentage points (33% from 45% in control schools) and the number of techniques used by 0.39 (27% from 1.43) in the midline, and raises them by 18.2 percentage points (63% from 29%) and 0.39 (53% from 0.73) in the endline. On the parent parcel, it raises the use of bed preparation by 10.9 percentage points (15% from 74% in control schools) and the number of techniques used by 0.36 (26% from 1.38 in control schools). All these strong effects are preserved when considering Lee lower bounds. Alternatively, the augmented SBAE program raises the number of techniques used by parents by 0.38 standard deviations — a sizable effect considering that parents are not directly trained in the program and that households do not receive other forms of interventions (e.g. provision of seeds or credit) than provision of knowledge and skills. By comparison, a large literature on sub-Saharan Africa (Suri and Udry, 2022) suggests that many village-based agricultural extension fails to create statistically significant impacts on farmers who are not directly trained, unless social network targeting (Beaman et al.,

2021) or incentives for trained farmers to communicate with others (BenYishay and Mobarak, 2019) are built into such extension programs. Figure 4 thus provides strong proof-of-concept that school-based agricultural education can be a highly effective method in increasing technology diffusion.

While Figure 4 focuses on the primary measures of adoption, Online Appendix Table OA5 indicates the augmented SBAE program is deepening agricultural intensification in a comprehensive way. I consider two secondary measures of agricultural intensification: first, whether the main yield-improving technique, bed preparation, is applied jointly with at least one of the three other soil management techniques, noting the potential of such pairing to increase yields; second, whether bed preparation is applied jointly with at least one deviation from three traditional cultivation practices (fallowing in previous rainy season; cultivation of roots or vegetables on rice fields; and intercropping with rice), noting the potential of such pairing to increase sales.

Whereas Figure 4 suggests that the SBAE program alone is entirely ineffective in increasing the use of bed preparation, Online Appendix Table OA5 provides a slightly different picture. Columns (6) and (10) indicate that the SBAE program, on its own, increases both students' and parents' joint use of bed preparation with other promoted techniques — by 8.8 percentage points for students (from 17%) and by 7.6 percentage points for parents (from 34%). By contrast, the SBAE program, on its own, has close to zero and statistically insignificant effects on whether students and parents use bed preparation along with deviations from traditional cultivation practices (columns (8) and (12)). While the promotional video intensifies students' and parents' use of bed preparation along with other techniques (columns (2) and (10); for students, only at midline), its main effect is to dramatically increase the use of bed preparation in settings deviating from traditional cultivation practices — by 12.1 percentage points for students (from 25%; column (8)) and 9.8 percentage points for parents (from 52%; column (12)). As in the case of primary measures of technology adoption, the annual farmer field day does not affect these secondary measures of technology adoption at endline. In summary, Online Appendix Table OA5 suggests that besides pivotally increasing the use of promoted techniques, the promotional video also dramatically increases the use of yield-improving techniques in settings that are more amenable to sales.

4.2.2 School attendance and time use

Figure 5 presents results on students' school attendance, with full estimates in Online Appendix Table OA6.

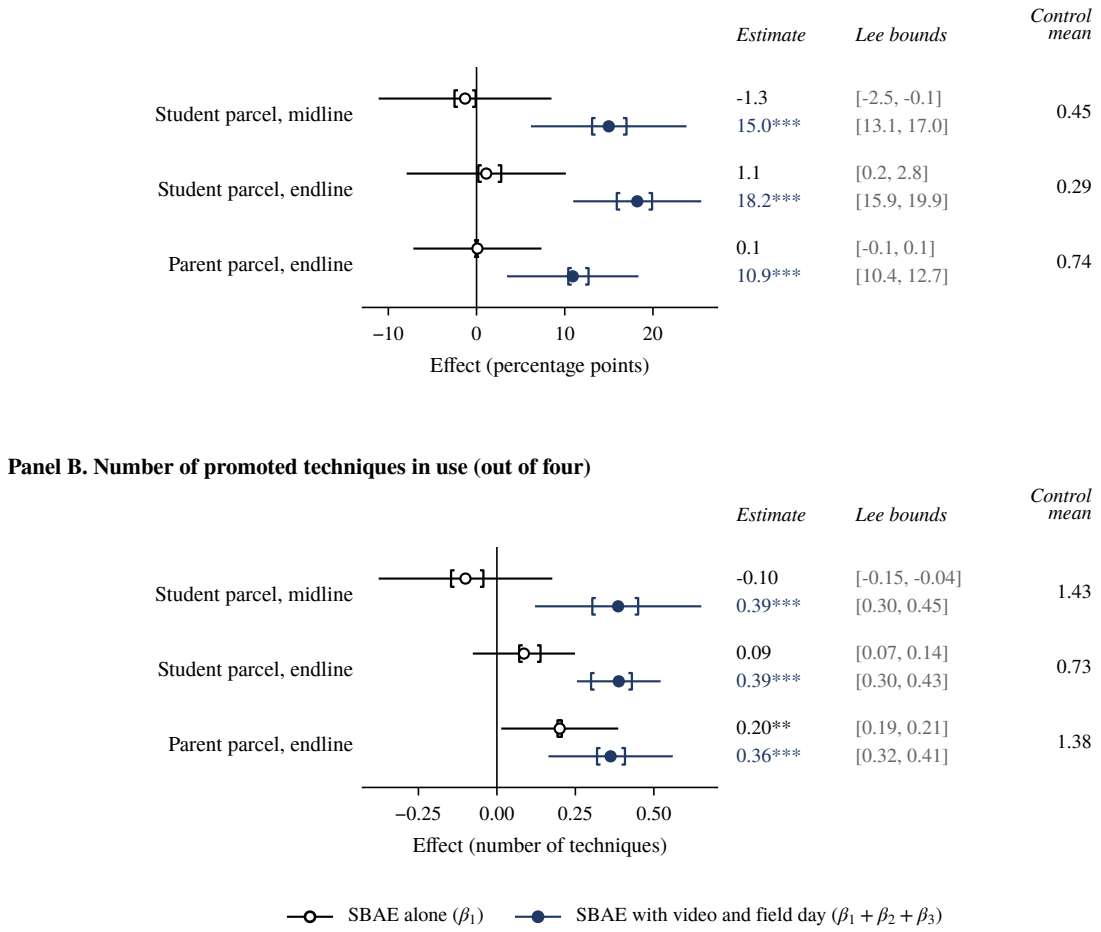


FIGURE 4. MAIN RESULTS: AGRICULTURAL TECHNOLOGY ADOPTION

Notes: This figure plots intent-to-treat effects estimated from (1). "SBAE alone" is the pure SBAE effect (β_1); "SBAE with video and field day" is the effect of SBAE augmented with both the promotional video and the annual farmer field day ($\beta_1 + \beta_2 + \beta_3$). Markers are point estimates and horizontal lines are 95% confidence intervals, based on standard errors clustered at the geographical-cluster level. Brackets on each confidence interval mark Lee (2009) lower and upper bounds. All specifications include pair-of-clusters fixed effects and an indicator for faith-based schools. Significance: *** p<0.01, ** p<0.05, * p<0.10. Outcomes are measured on the designated student parcel (midline and endline) and parent parcel (endline); "number of techniques" counts the four promoted soil management techniques. Full estimates are in Online Appendix Table OA4.

Figure 5 contrasts the effects of SBAE with and without parental engagement on attendance. These estimates provide three messages. First, without parental engagement, SBAE has no effect on dropouts, and the Lee lower bounds confirm that the SBAE program on its own increases student absenteeism. Second, parental engagement reduces dropouts by 4.5 percentage points in the midline and 5.0 percentage points in the endline (from 22% and 33% in control schools), both significant at the 5% level. The Lee bounds range from 4.0 to 6.5 percentage points in the midline and from 4.7 to 5.5 percentage points in the endline.[14] Third,

[14]There is a drop in the magnitude and precision of point estimates when moving from "SBAE + Video" to "SBAE + Video + FFD". This is caused by a negative but imprecise effect of the annual farmer field day on enrollment. Panel A therefore plots "SBAE + Video" (4.5 percentage points in the midline and 5 percentage points in the endline), which I take to be the upper bound of the true effect of the augmented SBAE program; "SBAE + Video + FFD" (3.8 percentage points in the midline and 3.9 percentage points in the endline) is the lower bound. Panels B and C plot "SBAE + Video + FFD", as do Figures 4 and 6 to 8.

including both types of parental engagement is sufficient to overturn the pure SBAE effect on absenteeism — reducing absenteeism by 18% in the midline (a drop of 0.12 from 0.69 out of 5 days) and by 27.8% in the endline (a drop of 0.18 from 0.65 out of 5 days); the endline reduction is statistically significant and robust to Lee bounds.

The last row of Figure 5 uses a single imputed measure of school attendance to account for the effects on both students' school enrollment and absenteeism. This measure counts the total number of school days students attend in the school year 2021/22 (year of the midline) to 2022/23 (year of the endline) with three imputation rules: first, days of absence are subtracted from a school year of 200 school days, assuming that the rate of absenteeism is constant throughout the year; second, students who have dropped out by the midline and endline surveys are counted as having zero school days in the corresponding school year; third, students who have switched schools are counted as having the same days of absence as the average among control school students who respond to surveys. Without parental engagement, SBAE has a small and statistically insignificant effect on overall school attendance (a drop of 3.6 days per student). The combined estimate of the SBAE program with both types of parental engagement indicates an increase in overall school attendance by 17.6 days per student (8% from 229.1 days in control schools). I will use this number in cost-benefit and cost-effectiveness analyses in Section 4.4.

Figure 6 presents results on students' time use (full estimates in Online Appendix Table OA7), with treatment effects on studying hours that mirror those on absenteeism.

Figure 6 provides two messages. First, the SBAE program on its own reduces students' studying hours; in the endline, even the Lee upper bound is significantly negative. Second, including both types of parental engagement is sufficient to overturn the pure SBAE effect — increasing students' studying hours by 7% in the midline (statistically insignificant) and by 21.7% in the endline (an increase of 1.17 hours from 5.39 hours per week).

To complete the description of students' time use, the last two rows of Figure 6 show students' weekly hours spent on farming (inclusive of hours spent on school farms). Neither SBAE alone nor SBAE with both types of parental engagement increases students' farming hours significantly relative to control schools — rebutting concerns that SBAE might increase child labor.

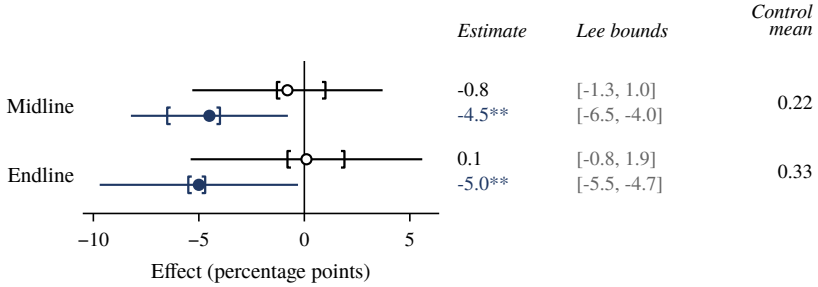
4.2.3 Students' livelihoods and aspirations

Figure 7 presents results on students' farm sales, non-farm income, total income, and savings in 2022, retrospectively reported in the endline survey, with full estimates in Online Appendix Table OA8. For each outcome, I estimate effects at the extensive margin (whether students have positive values), the intensive margin (log values among students with positive outcomes), and overall percentage changes using Poisson regression. All monetary values are expressed in 2022 Liberian dollars and winsorized at the 2.5 and 97.5 percentiles.

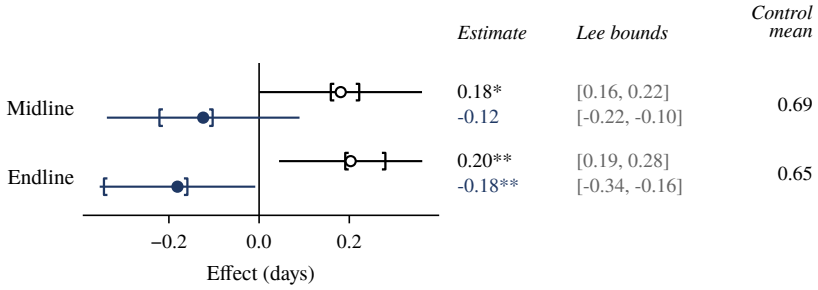
Figure 7 shows that, without parental engagement, SBAE has no significant effect on students' farm sales, reduces the fraction of students with non-farm income by 6.1 percentage points, and has no significant effect on total income or savings. With both types of parental engagement, SBAE increases the fraction of students with farm sales by 9.6 percentage points (14% from 70% in control schools), with a statistically insignificant 14% increase in farm sales in the Poisson specification (from 3,407 Liberian dollars). Its effects on non-farm income and total income are small and statistically insignificant. Most notably, it increases the fraction of students with positive savings by 10.7 percentage points (19% from 55% in control schools) and total savings by 21% in the Poisson specification (significant at the 10% level; from a baseline of approximately US$20 annually).

While students' increases in farm sales tend to be offset by decreases in non-farm income, the measurement of total income likely understates actual gains from the program, since many students work as assistants to household members and do not directly sell farm produce. Savings provide a better measure of students'

Panel A. Dropped out of school (percentage points)



Panel B. Days absent in the last five school days



Panel C. Total days of school attendance, 2021/22 to 2022/23 (imputed)

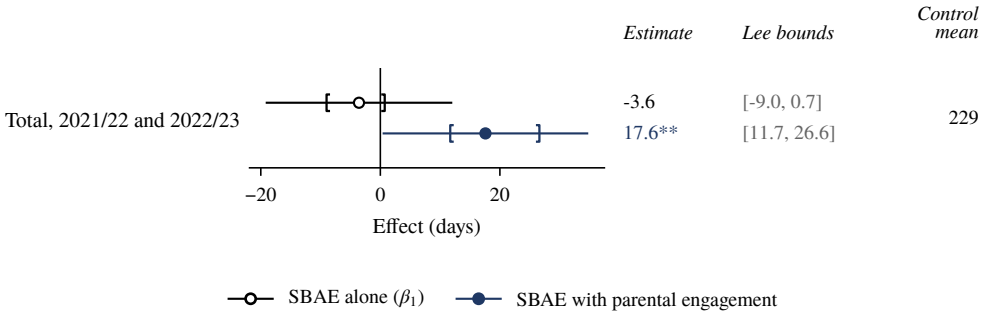
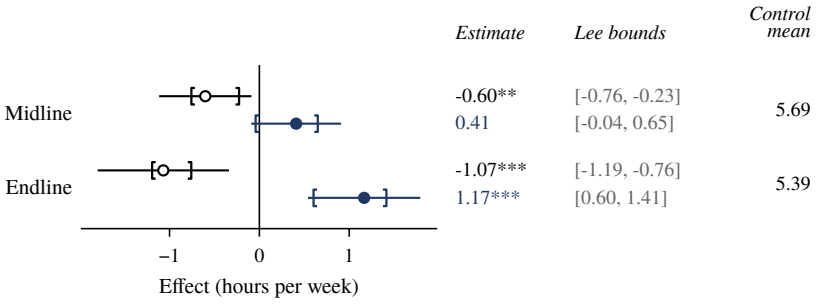


FIGURE 5. MAIN RESULTS: SCHOOL ATTENDANCE

Notes: This figure plots intent-to-treat effects estimated from (1). "SBAE alone" is the pure SBAE effect (β_1). "SBAE with parental engagement" is the effect of SBAE augmented with the promotional video in Panel A ($\beta_1 + \beta_3$) and with both the video and the annual farmer field day in Panels B and C ($\beta_1 + \beta_2 + \beta_3$); the field day has a negative and imprecise effect on enrollment, so for dropout the combination that includes it is reported in the accompanying footnote and in Online Appendix Table OA6. Markers are point estimates and horizontal lines are 95% confidence intervals, based on standard errors clustered at the geographical-cluster level. Brackets on each confidence interval mark Lee (2009) lower and upper bounds. All specifications include pair-of-clusters fixed effects and an indicator for faith-based schools. Significance: *** p<0.01, ** p<0.05, * p<0.10. "Dropped out" is one minus the enrollment indicator in Online Appendix Table OA6, so its estimates and Lee bounds have the opposite sign to those in the table. Total days of attendance over 2021/22–2022/23 is imputed as described in Section 3.4. Full estimates are in Online Appendix Table OA6.

Panel A. Hours studying per week



Panel B. Hours farming per week

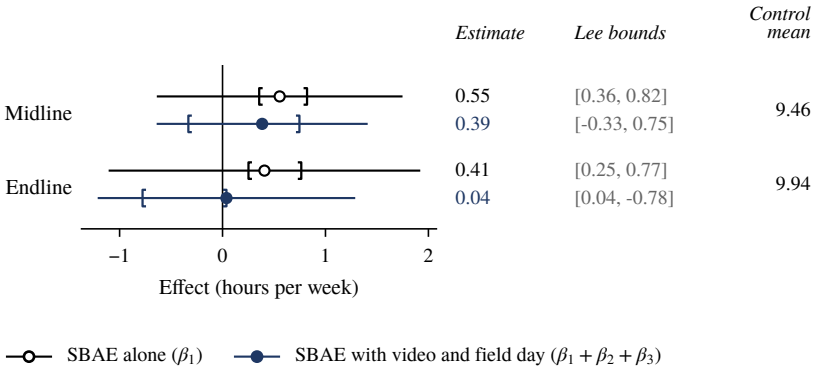


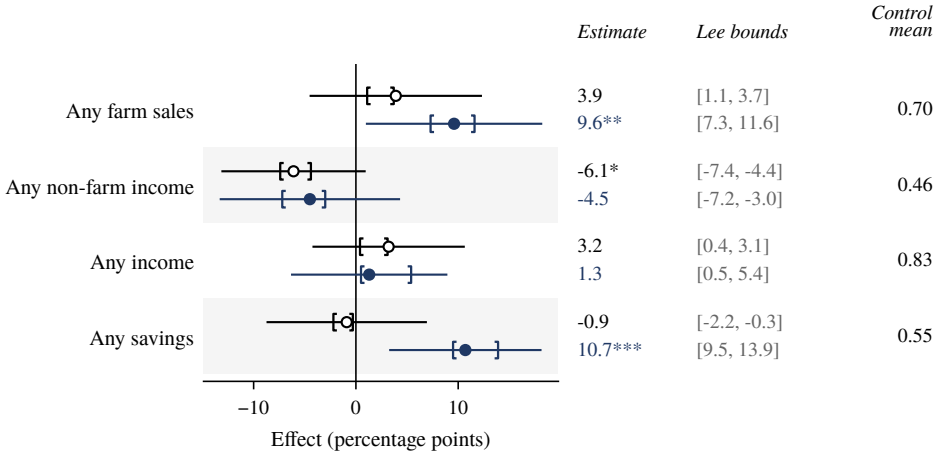
FIGURE 6. MAIN RESULTS: STUDENTS' TIME USE

Notes: This figure plots intent-to-treat effects estimated from (1). "SBAE alone" is the pure SBAE effect (β_1); "SBAE with video and field day" is the effect of SBAE augmented with both the promotional video and the annual farmer field day ($\beta_1 + \beta_2 + \beta_3$). Markers are point estimates and horizontal lines are 95% confidence intervals, based on standard errors clustered at the geographical-cluster level. Brackets on each confidence interval mark Lee (2009) lower and upper bounds. All specifications include pair-of-clusters fixed effects and an indicator for faith-based schools. Significance: *** p<0.01, ** p<0.05, * p<0.10. Hours are for the week preceding each survey; farming hours include hours on school farms. Full estimates are in Online Appendix Table OA7.

economic gains in this context, as they reflect transfers from household members in addition to direct earnings. The combined parental engagement interventions significantly increase savings beyond the SBAE-only effect (p=0.04 for the joint test). Online Appendix Table OA9 confirms that this increase in savings stems from higher income rather than reduced consumption—the SBAE program has close to zero and statistically insignificant effects on students' overall spending (Poisson specification) and meal consumption, with or without parental engagement.

Turning to the last category of primary outcomes, Figure 8 shows results on students' aspirations in the midline and endline surveys, with full estimates in Online Appendix Table OA10. Parental engagement is what raises students' study of agriculture as an elective subject: SBAE alone has no significant effect, whereas SBAE with both types of parental engagement increases it by 18.4 percentage points (from 50% in control schools). SBAE alone increases students' naming of agricultural careers by 7.8 percentage points (from 43% in control schools), while including both types of parental engagement intensifies this effect to 11.5 percentage points over control schools. Finally, SBAE alone has no significant effect on students' saving for university, whereas SBAE with both types of parental engagement increases it by 6.4 percentage points (from 17% in control schools) — an effect driven by the annual farmer field day (Section 4.3).

Panel A. Any income or savings in the past year (percentage points)



Panel B. Amounts in Liberian dollars (Poisson coefficients)

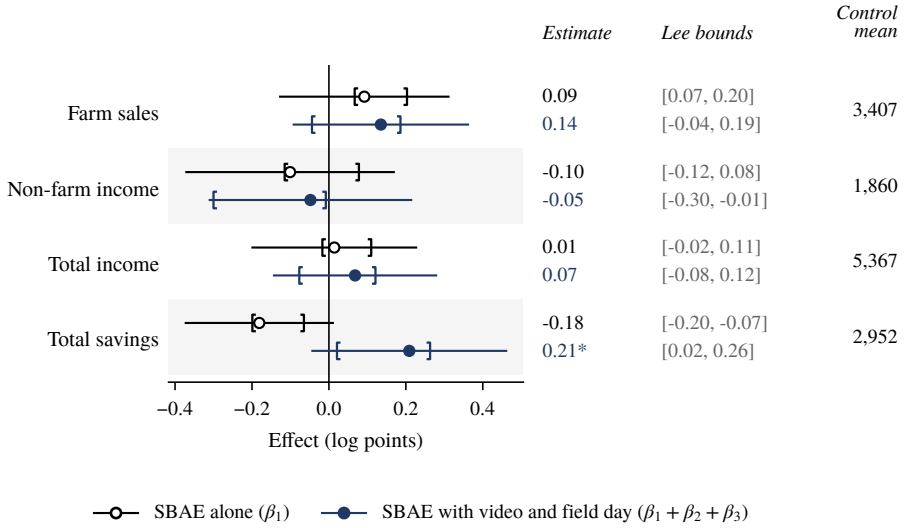


FIGURE 7. MAIN RESULTS: STUDENTS' INCOME AND SAVINGS

Notes: This figure plots intent-to-treat effects estimated from (1). "SBAE alone" is the pure SBAE effect (β_1); "SBAE with video and field day" is the effect of SBAE augmented with both the promotional video and the annual farmer field day ($\beta_1 + \beta_2 + \beta_3$). Markers are point estimates and horizontal lines are 95% confidence intervals, based on standard errors clustered at the geographical-cluster level. Brackets on each confidence interval mark Lee (2009) lower and upper bounds. All specifications include pair-of-clusters fixed effects and an indicator for faith-based schools. Significance: *** p<0.01, ** p<0.05, * p<0.10. Outcomes refer to the midline year (2022), reported retrospectively at endline, in Liberian dollars (L$) winsorized at the 2.5th and 97.5th percentiles. "Any" outcomes are extensive-margin indicators estimated by OLS; the other outcomes are estimated by Poisson regression, whose coefficients approximate proportional changes and are reported directly in the "vs. control" column. Intensive-margin estimates and full estimates are in Online Appendix Table OA8.

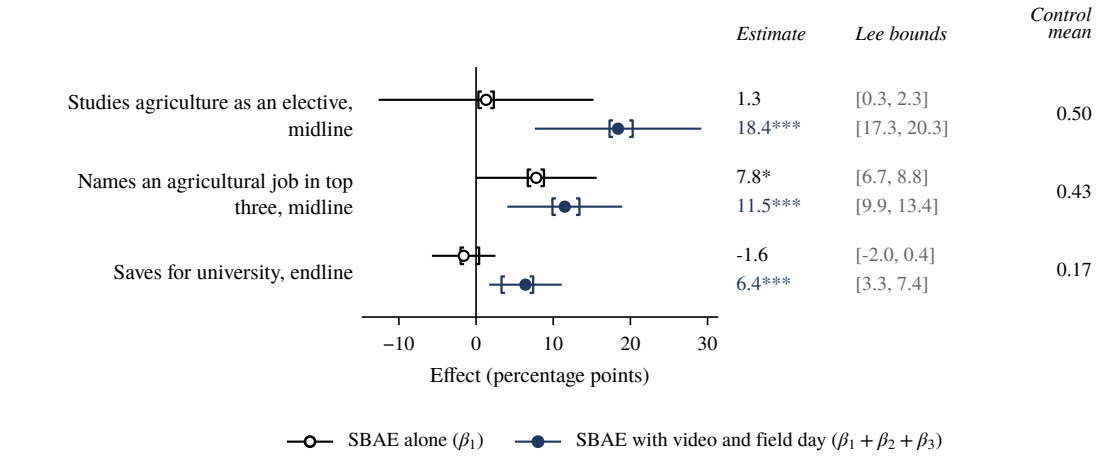


FIGURE 8. MAIN RESULTS: STUDENTS' ASPIRATIONS

Notes: This figure plots intent-to-treat effects estimated from (1). "SBAE alone" is the pure SBAE effect (β_1); "SBAE with video and field day" is the effect of SBAE augmented with both the promotional video and the annual farmer field day ($\beta_1 + \beta_2 + \beta_3$). Markers are point estimates and horizontal lines are 95% confidence intervals, based on standard errors clustered at the geographical-cluster level. Brackets on each confidence interval mark Lee (2009) lower and upper bounds. All specifications include pair-of-clusters fixed effects and an indicator for faith-based schools. Significance: *** p<0.01, ** p<0.05, * p<0.10. Agricultural jobs include farmer, agronomist and extension officer, named without prompting. Full estimates are in Online Appendix Table OA10.

4.2.4 Summary and robustness to multiple hypothesis testing

In summary, Figures 4 to 8 all suggest the pivotal role of parental engagement in SBAE's effectiveness. Whereas SBAE on its own falls short of its goals (Section 5.3), SBAE augmented with both types of parental engagement is sufficient to achieve all desired goals: (i) increasing parents' adoption of promoted techniques by 0.38 standard deviations; (ii) reducing absenteeism by 27.8% and dropouts by 4 to 5 percentage points; (iii) increasing students' weekly studying hours by 21.7%; (iv) increasing the fraction of students with savings by 10.7 percentage points and their total savings by 21% without sacrificing their spending and meals consumption; and (v) increasing the fraction of students who find an agricultural career favorable and save for attending university.

To economize on space, Figures 4 to 8 and the corresponding appendix tables have not shown robustness checks with respect to multiple hypothesis testing. Online Appendix Figure OA1 addresses this issue by plotting the naive p-values and adjusted q-values based on the procedure of Anderson (2008), which controls the false discovery rate across multiple tests. To be specific, I conduct two types of adjustments: (i) pooling all 18 outcomes together and adjusting for the four linear combination coefficients tested (SBAE, SBAE + Video, SBAE + FFD, and SBAE + Video + FFD) — thus 72 tests in total, disregarding potential correlations between outcomes, such as between students' and parents' adoption; (ii) pooling only outcomes within pre-specified categories: testing 6 outcomes for 4 coefficients under "technology adoption"; testing 3 outcomes for 4 coefficients under "school attendance and learning"; testing 2 outcomes for 4 coefficients under "income and savings"; testing 4 outcomes for 4 coefficients under "spending and food security"; and testing 3 outcomes for 4 coefficients under "aspirations".

Online Appendix Figure OA1 presents the robustness of ten main results for the augmented SBAE program with promotional video and the annual farmer field day. Seven out of ten results have p-values below 0.01 before correction, and seven out of ten have adjusted q-values below 0.05 under both adjustments. For the remaining results (total days of attendance, farm sales, savings), the adjusted q-values range from 0.10 to

0.67. Hence the effects of the augmented program on technology adoption, studying hours, and aspirations are robust to multiple hypothesis testing, whereas its effects on total days of attendance and on students' farm sales and savings should be interpreted with more caution.

4.3 Marginal effects of the promotional video and the farmer field day

Figure 9 separates the contributions of the two forms of parental engagement. For every primary outcome, it plots the marginal effect of the promotional video (β_3 in (1)) and of the annual farmer field day (β_2), each scaled by the control-school mean.

The promotional video, which is experimentally designed to reach every parent, plays an especially important role in parental engagement (Panel A of Figure 9). First, it raises technology adoption on all six measures. On the student parcel, it raises both the use of bed preparation and the number of techniques used in the midline (by 10.8 percentage points from 45% in control schools, and by 0.28, 20% from 1.43) and in the endline (by 10.4 percentage points from 29%, and by 0.18, 24% from 0.73). It is also the only treatment that raises adoption on the parent parcel — increasing the use of bed preparation by 8.8 percentage points (from 74% in control schools) and the number of techniques used by 0.24 (18% from 1.38 in control schools). Second, only the promotional video reduces dropouts, by 5 percentage points by the endline (from 33% in control schools); its effects on absenteeism are negative but statistically insignificant; and it is the only treatment that increases overall school attendance, by 19.2 days per student. Third, it increases students' weekly studying hours by 12.4% in the midline (0.71 hours from 5.69 hours per week) and by 20.7% in the endline (1.12 hours from 5.39 hours per week), without increasing their farming hours. Fourth, only the promotional video increases the fraction of students with farm sales (by 8.4 percentage points, 12% from 70% in control schools), while its estimated effect on students' non-farm income is negative (18.5% lower in the Poisson specification) but statistically insignificant. Fifth, only the promotional video increases students' studying of agriculture as an elective subject, by 11.7 percentage points (23% from 50% in control schools).

While the annual farmer field day, which is organized at the school level, has quantitatively smaller effects on technology adoption, dropouts, and overall school attendance, it is nonetheless an important supplement in making SBAE complete (Panel B of Figure 9). This can be seen in several ways: (i) it speeds up students' adoption of technologies — its effects on the student parcel are positive throughout but statistically significant only for the number of techniques used in the midline (an increase of 0.21, 14% from 1.43 in control schools), and it has no effect on the parent parcel; (ii) it is crucial in ensuring the overturn of SBAE effects on absenteeism and studying hours — reducing endline absenteeism by 42% (a drop of 0.28 from 0.65 out of 5 days) and increasing endline studying hours by 20.8% (1.12 hours from 5.39 hours per week), while together with the promotional video it reverses the SBAE-induced increase in absenteeism (although some marginal effects are not statistically significant, the joint tests reject the null that applying both types of parental engagement has no effects on absenteeism relative to SBAE-only schools, with p = 0.06 in the midline and p = 0.01 in the endline); (iii) it ensures that students' farming hours do not increase; (iv) it is crucial in ensuring positive effects on students' savings, increasing total savings by 23% in the Poisson specification; and (v) only it increases the fraction of students who save for attending university, by 7.5 percentage points (44% from 17% in control schools).

4.4 Cost-benefit and cost-effectiveness analyses

The previous sections show that SBAE, when augmented with both parental engagement treatments, is highly effective in increasing students' savings, school attendance, and parents' adoption of agricultural technologies. But do these benefits justify the costs and is the augmented SBAE program cost-effective? This section summarizes back-of-the-envelope calculations; the appendix on cost-benefit and cost-effectiveness analyses details all assumptions (Appendix Table B1) and presents the full results (Appendix Figures B1 to B3).

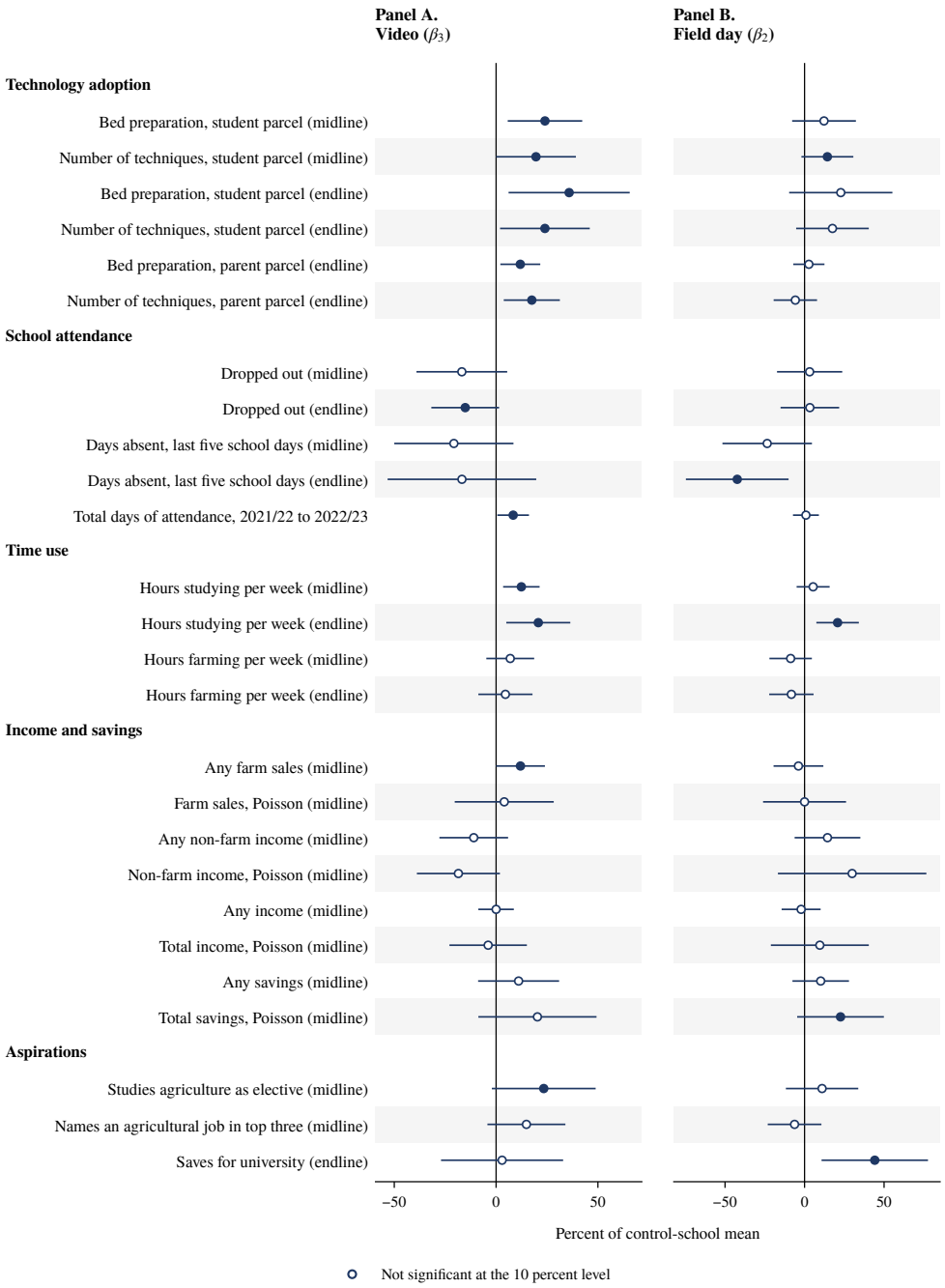


FIGURE 9. MARGINAL EFFECTS OF THE PROMOTIONAL VIDEO AND THE FARMER FIELD DAY

Notes: This figure plots the marginal effects of the two parental engagement treatments estimated from (1): β_3 (SBAE × Video; Panel A) and β_2 (SBAE × FFD; Panel B). Because (1) is the short model, each marginal effect averages over SBAE schools with and without the other treatment. Estimates and 95% confidence intervals are divided by the control-school mean; "dropped out" is one minus the enrollment indicator. Poisson estimates are proportional changes and are shown without rescaling. Standard errors are clustered at the geographical-cluster level. Filled markers denote estimates significant at the 10% level. Lee bounds are reported for the treatment combinations in Figures 4 to 8; full estimates are in Online Appendix Tables OA4 to OA10.

Costs. Over the three-year trial, the augmented SBAE program costs $801,139 (2023 US dollars), or about $40 per student: $621,139 for program implementation and $180,000 for parental engagement. Because setup costs are not repeated and monitoring visits can be curtailed to once a year while teacher training is retained, total costs drop by 63% after the initial three years.

Cost-benefit analysis. I monetize three benefits: the increase in students' savings; students' discounted lifetime earnings from additional days of school attendance ($1.89 per day, assuming an 8% annual return to schooling and a 10% discount rate); and parents' net production value from adopting bed preparation, calculated conservatively. Over the first three years, benefits exceed costs, yielding a benefit-cost ratio of 1.33 (Appendix Figure B1). Even when excluding benefits from parents' technology adoption, the benefit-cost ratio remains at 0.98 — the benefits accruing to students alone nearly justify the program. This calculation counts technology adoption benefits for a single season only, omits spillovers to neighboring farmers, and does not allow educational returns to grow as SBAE scales and incorporates complementary interventions that improve the quality of instruction. Once school capacity is built and monitoring costs fall, the ratio rises further: over a ten-year horizon, the cumulative benefit-cost ratio is 1.53 if annual benefits decline to 50% after the first three years, and 2.36 if they are sustained (Appendix Figure B2).

Cost-effectiveness analysis. I compare SBAE's impact per $100 with other African programs evaluated using randomized trials (Appendix Figure B3). For technology adoption, SBAE induces 0.46 to 0.94 households to adopt bed preparation per $100, or 0.55 to 1.02 households to adopt bed preparation *and* a complementary soil management technique, depending on spillovers to non-parent farmers. This far exceeds extension programs using the contact farmer model (0.11 households per $100 in Kondylis et al., 2017) and farmer field days promoting fertilizer (0.15 to 0.46 in Fabregas et al., 2023). It is comparable to video-mediated extension (0.62 in Van Campenhout et al., 2021) and to village-based extension with performance incentives for contact farmers when promoting pit planting (0.60 in BenYishay and Mobarak, 2019), which outperforms SBAE only when promoting composting (1.53). For school attendance, the augmented SBAE program generates 43.46 additional days per $100 — 1.7 to 2.5 times as cost-effective as conditional cash transfers in Malawi (17.06 to 24.98 days per $100 in Baird et al., 2011).

Overall, these back-of-the-envelope calculations provide strong support of the merits of the augmented SBAE program, at least in the context of Liberia. First, SBAE is highly sustainable — it offers a stream of benefits that increasingly outweigh costs after external support for schools is dropped. Second, in terms of cost-effectiveness, SBAE compares favorably with major alternatives in diffusing agricultural technologies and increasing school attendance. The appendix discusses how these results may generalize to countries higher up the ladder of economic development.

5 Mechanisms

Section 4 provides evidence that the SBAE program only succeeds in achieving its goals when parental engagement treatments are included. This section addresses the question of why. I begin by noting that sampled students have baseline farming experiences but may not have participated in the program. So a natural guess would be: parental engagement works by raising students' responses to training in the SBAE program and thus the ITT effects we observe in Section 4.

5.1 SBAE's training effects are not driven by parental engagement

I first document SBAE's training effects on teachers and students, and then show that parental engagement does not drive them.

5.1.1 SBAE impact on teachers

To show that the program is effective in training teachers, we begin by documenting SBAE's impact on teachers, which was measured during the midline and endline surveys. I estimate

$$Y_{tscp} = \alpha + \beta_1 \, \text{SBAE}_p + \gamma_p + \varepsilon_{tscp}, \tag{2}$$

where Y_{tscp} is the outcome of interest for teacher t, school s, geographical cluster c, and pair-of-clusters p; SBAE_p indicates whether pair p is randomly assigned to the SBAE arm; γ_p denotes randomization pair fixed effects; ε_{tscp} is an error term. Standard errors are clustered at the geographical cluster level, which is the highest level at which random assignment took place. β_1 is the coefficient of interest, capturing the ITT effects of SBAE on teachers.

Figure 10 presents the results, with full estimates in Online Appendix Table OA11. The first four estimates indicate consistently positive ITT effects of SBAE on teachers' knowledge about promoted techniques and beliefs about students' attainable yields, in both the midline and endline surveys. Teachers' scores on knowledge tests improve by 12% (0.4σ) and 14% (0.44σ) respectively. Teachers' beliefs about students' attainable cassava tubers in 9-10 months improve by 24% (0.53σ) and 20% (0.42σ) respectively. The large magnitude of these ITT effects validates both (i) the strong receptiveness among teachers and (ii) the novelty of SBAE's agricultural curriculum, considering that 67 out of 97 control schools also have school gardens and most teachers farm outside schools. The last two estimates indicate also positive ITT effects of SBAE on teachers' pedagogy in the endline survey.[15] 12.6 percentage points more students report that their teachers have used agricultural projects or field visits in instruction in the last five days. Students also report a 25% (0.23σ) increase in the number of scientific concepts that teachers have ever demonstrated with farm work. Taken together, Figure 10 thus indicates that the SBAE program has strong effects on teachers as intended.

5.1.2 Early training effects on students

Now we analyze SBAE's impact on students. We first discuss the results of the first follow-up survey, which captured training effects by 5-7 months, and importantly, before parental engagement treatments were implemented. I estimate

$$Y_{hscp} = \alpha + \beta_1 \, \text{SBAE}_p + \gamma_p + \varepsilon_{hscp}, \tag{3}$$

where Y_{hscp} is the outcome of interest for household h, school s, geographical cluster c, and pair-of-clusters p; SBAE_p indicates whether pair p is randomly assigned to the SBAE arm; γ_p denotes randomization pair fixed effects; ε_{hscp} is an error term. Standard errors are clustered at the geographical cluster level, which is the highest level at which random assignment took place. β_1 is the coefficient of interest, capturing the ITT effects of SBAE on students.

Figure 11 presents the results, with full estimates in Online Appendix Table OA12. The first four estimates indicate consistently positive ITT effects of SBAE on students' exposure to promoted farming techniques. The fractions of students who have ever used bed preparation and composting improve by 4 and 6 percentage points respectively. Reflecting SBAE's training on farm management skills, students' knowledge about site selection improves by 3% (0.08σ). Most importantly, students' beliefs about students' attainable cassava tubers in 9-10 months improve by 4% (0.09σ) — these early improvements in beliefs are consistent with descriptions in agronomic trials that report early, visible differences in the height of stems and the size of leaves when bed preparation is applied. To verify that these changes in beliefs are due to promoted techniques in the SBAE program, the fifth estimate shows that there are no changes in students' beliefs about cassava tubers attained by typical farmers in their communities. The last three estimates indicate ITT effects on

[15] In the Online Appendix, I show similar positive ITT effects on teachers' pedagogy in the midline survey. The results are also robust to using teacher reports.

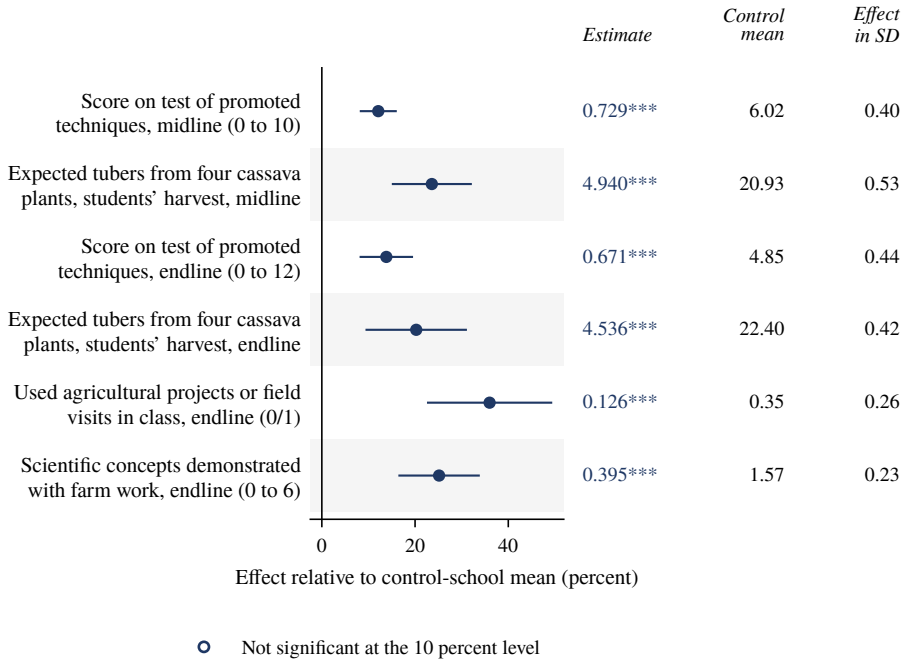


FIGURE 10. MIDLINE AND ENDLINE INTENT-TO-TREAT EFFECTS ON TEACHERS

Notes: This figure plots intent-to-treat effects of SBAE on agriculture and science teachers, estimated from (2). The left panel plots each estimate and its 95% confidence interval divided by the control-school mean; hollow markers denote estimates that are not significant at the 10% level. The right panel reports the estimate in original units, the control-school mean, and the estimate divided by the control-group standard deviation. All regressions include pair-of-clusters fixed effects; standard errors are clustered at the geographical-cluster level. Test scores are on promoted agricultural techniques; expected tubers are teachers' beliefs about the number of tubers students can harvest in 9–10 months from 4 cassava plants. The two pedagogy outcomes are student reports: whether teachers used agricultural projects or field visits in science instruction in the past five days, and the number of scientific concepts teachers have demonstrated using farm work. Full estimates are in Online Appendix Table OA11. Significance: *** p<0.01, ** p<0.05, * p<0.10.

students' behavior outside schools. The fraction of students who report intending to look after a farm outside school in the first rainy season improves by 9 percentage points from the control mean of 60%. Meanwhile, there are early signs of pitfalls as discussed in the Introduction — students' weekly studying hours drop by 5% and farming hours increase by 2%, though the latter is not statistically significant at conventional levels. Taken together, Figure 11 thus indicates that before parental engagement, the SBAE program had already increased students' intentions to start home projects and apply promoted techniques outside schools, with some diversion of students' efforts from academic studies.

5.1.3 Do stronger responses to SBAE training account for the difference?

Figure 12 examines this possibility by estimating midline and endline treatment effects on key intermediate outcomes associated with students' training in the SBAE program; full estimates are in Online Appendix Table OA13. Mirroring results in the first follow-up survey (Section 5.1.2), the odd-numbered columns of Online Appendix Table OA13 indicate that the overall SBAE effect is positive as expected — 73.7% and 84.3% of sampled students in SBAE schools had participated in the program by the midline and endline surveys; SBAE school students scored 6.8% and 5.7% higher than control school students on tests of promoted techniques in the midline and endline; 5.8 and 7.9 percentage points more students in SBAE schools believed that they

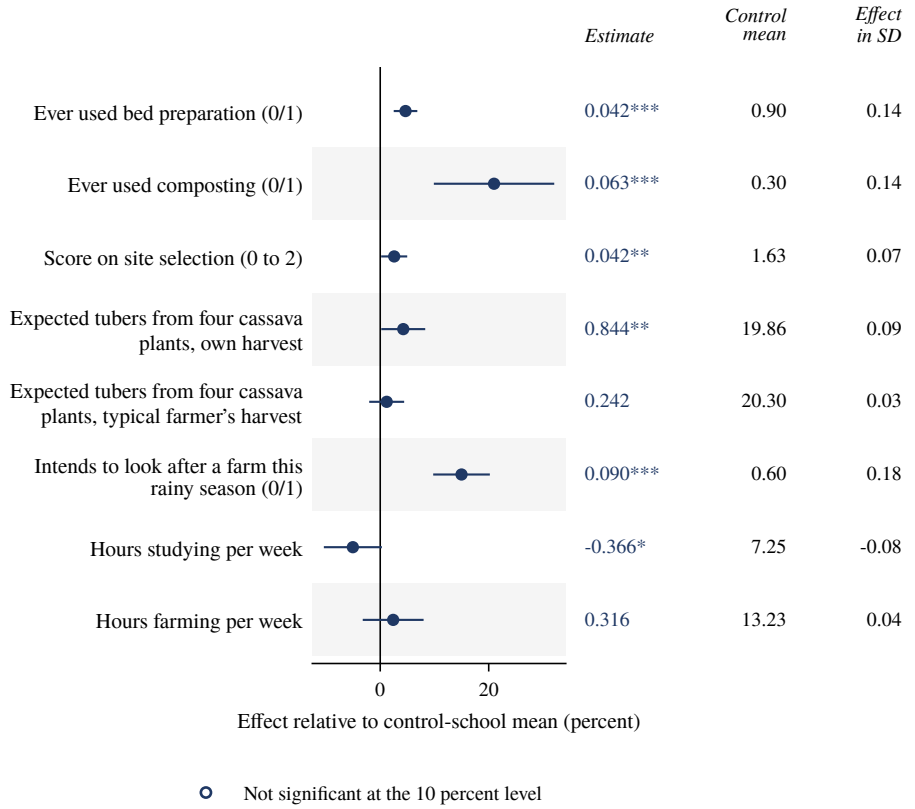


FIGURE 11. INTENT-TO-TREAT EFFECTS ON STUDENTS IN THE FIRST FOLLOW-UP SURVEY

Notes: This figure plots intent-to-treat effects of SBAE on students in the first follow-up survey, before the parental engagement treatments, estimated from (3). The left panel plots each estimate and its 95% confidence interval divided by the control-school mean; hollow markers denote estimates that are not significant at the 10% level. The right panel reports the estimate in original units, the control-school mean, and the estimate divided by the control-group standard deviation. All regressions include pair-of-clusters fixed effects; standard errors are clustered at the geographical-cluster level. Expected tubers are students' beliefs about the number of tubers that they (own harvest) or a typical farmer in their community can harvest in 9–10 months from 4 cassava plants. Hours are for the week preceding the survey. Full estimates are in Online Appendix Table OA12. Significance: *** p<0.01, ** p<0.05, * p<0.10.

could harvest more cassava tubers per plant than a typical adult farmer in the community.

Figure 12 shows that most student participation in the program is driven by SBAE alone. Specifically, 67.7% of sampled students in SBAE-only schools had participated by the midline, and the promotional video added only 13.2% of students to the program. By the endline, 80.9% of sampled students in SBAE-only schools had participated, whereas the promotional video had no statistically significant effects on program participation. The evidence thus suggests that the promotional video merely speeds up SBAE participation, and only by a small fraction. For increased SBAE participation to explain the dramatic effects of parental engagement — large differentials on technology adoption and reversed effects on education — we would expect marginal effects of parental engagement on SBAE participation that are large relative to pure SBAE effects.

Of course, parental engagement could have intensified students' absorption of SBAE training, even if participation remains unchanged. However, another closer inspection — of the test scores and beliefs in Figure 12 — suggests that SBAE alone drives the improvements in students' agricultural knowledge (at midline) and beliefs, whereas the parental engagement treatments have no statistically significant positive effects on them.

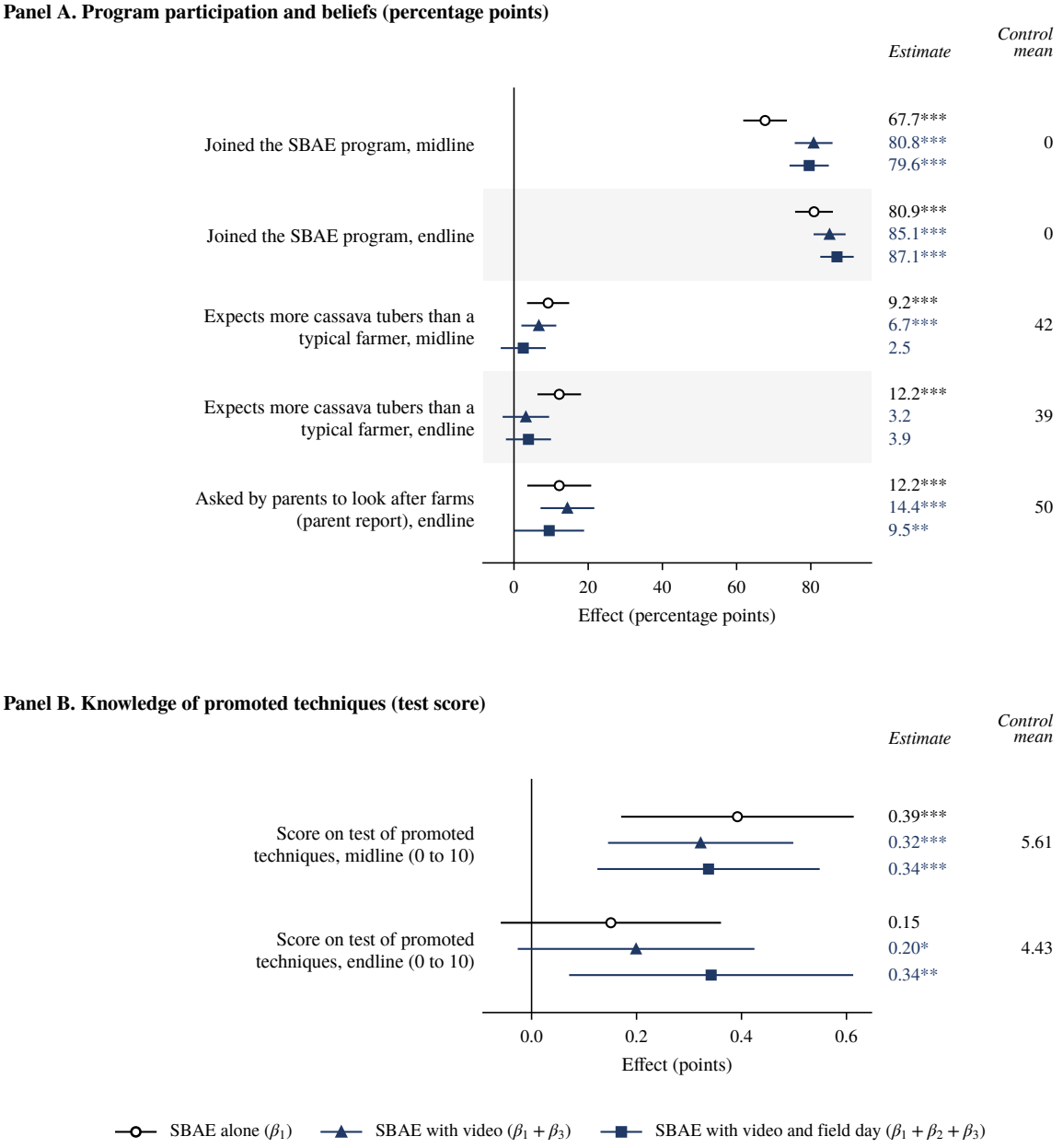


FIGURE 12. MIDLINE AND ENDLINE INTENT-TO-TREAT EFFECTS ON STUDENTS' TRAINING OUTCOMES

Notes: This figure plots intent-to-treat effects estimated from (1) for SBAE alone (β_1; hollow circles), SBAE with the promotional video ($\beta_1+\beta_3$; triangles), and SBAE with both the promotional video and the annual farmer field day ($\beta_1+\beta_2+\beta_3$; squares). Panel A reports indicator outcomes in percentage points; Panel B reports scores on the test of promoted techniques (0–10). Horizontal bars are 95% confidence intervals based on standard errors clustered at the geographical-cluster level. "Joined the SBAE program" is zero in control schools by construction. "Student asked to look after farms" is a parent report from the endline survey; all other outcomes are student reports. Full estimates, including the overall SBAE effect that pools all SBAE schools, the field day combination ($\beta_1 + \beta_2$) and Lee bounds, are in Online Appendix Table OA13. Significance: *** p<0.01, ** p<0.05, * p<0.10.

For increased students' absorption of SBAE training to explain the dramatic effects of parental engagement, we would expect that parental engagement treatments at least exert some effects on students' agricultural knowledge and beliefs.

So far we have examined measures that capture SBAE's impact within schools. But an important part of SBAE is for students to become agents of diffusion. Could it be that students only increased their intentions to look after household farms upon parental engagement? However, results in the first follow-up survey (Section 5.1.2) suggest that SBAE increased students' intentions to look after household farms before parental engagement. The last indicator in Panel A of Figure 12 further examines this from endline parent reports — whether students have asked to look after farms in the last two years. SBAE alone increases this measure by 12.2 percentage points (from 50% in control schools), whereas the promotional video and the annual farmer field day have no statistically significant additional effects.

To sum up, the evidence suggests that the pivotal effects of parental engagement on primary outcomes cannot be driven by students' program participation, absorption of SBAE training, or intentions to look after household farms — SBAE alone accounts for these changes.

5.2 Parental engagement enables intra-household diffusion mechanisms otherwise muted

Having shown that SBAE alone is sufficient to equip students as agents of diffusion, we now turn to another possibility: parents do not act on what students bring home unless they are engaged, even though students are willing to apply the promoted techniques. I focus specifically on the dual diffusion mechanisms mentioned in the Introduction: (i) parents' visits to schools; (ii) students' home projects, intra-household communication, and parents' observations.

Parents' visits to schools. Figure 13 shows results on parents' visits to schools and related outcomes, with full estimates in Online Appendix Table OA14. Columns (1) and (3) of that table indicate that, in line with a larger fraction of SBAE schools (100%) having school farms than control schools (69%), SBAE overall has increased the fraction of parents who have visited school farms and the number of visits parents make in the second rainy season.

However, parents' visits to school farms are far from mechanical. First, only a small fraction of SBAE-only school parents visit school farms — 43.9%, as opposed to 33% in control schools — whereas including both types of parental engagement into the SBAE program increases this fraction to 65.3%. Second, and most surprisingly, SBAE alone does not increase the number of visits that parents make in the second rainy season. Including both types of parental engagement increases this measure by 0.94, which means doubling visits from control schools (0.89 per parent). Third, and most importantly, including both types of parental engagement is crucial in enabling more parents to observe harvests on the school farm, from 37.9% in SBAE-only schools to 61.1%.

Besides visits to school farms, Figure 13 also examines parents' attendance of parent-teacher meetings, which could be crucial in encouraging parents' monitoring of students' academic studies and school attendance. In line with treatment effects on students' absenteeism and studying hours (Section 4.2.2), Figure 13 indicates a reversal of effects on parents' attendance of parent-teacher meetings. With SBAE only, parents' interest in attendance surprisingly drops — 10.2 percentage points fewer parents attend meetings (from 36% in control schools) and the number of meetings attended in 2022/23 drop by 38.7% (a drop of 0.35 from 0.91 in control schools). Both the promotional video and the annual farmer field day contribute to a reversal in attendance — when included together in the SBAE program, 12.2 percentage points more parents attend (relative to 36% in control schools) and the number of meetings attended increase by 37%. These results indicate that, in line with potential concerns about SBAE, the program alone could distract parents' attention from students' academics — whereas the inclusion of parental engagement helps to reverse this distraction.

Is there further evidence that substantiates the impact of parents' visits to schools? The last two rows of Panel B of Figure 13 examine if these visits increase parents' learning of promoted techniques. Specifically, I

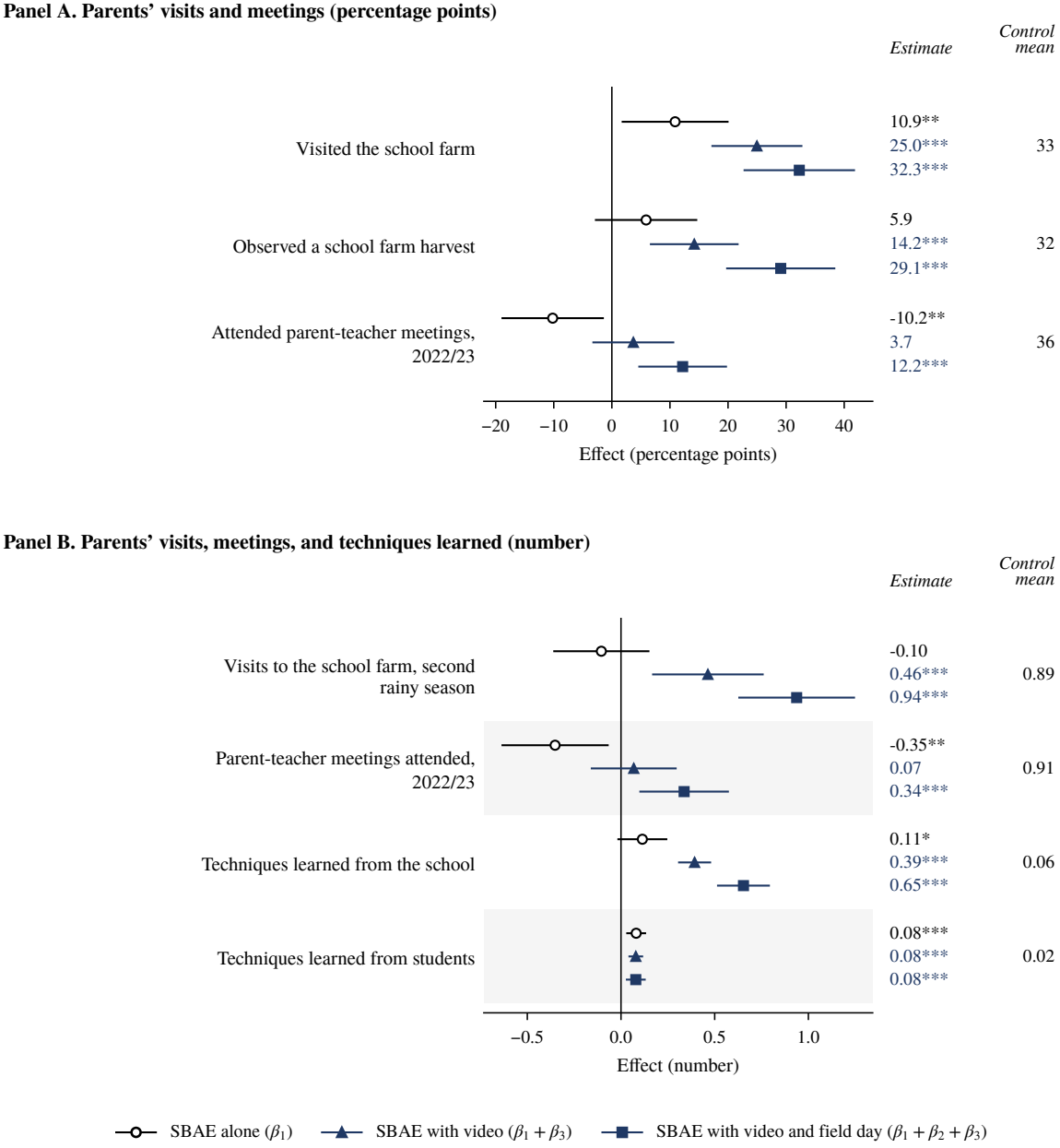


FIGURE 13. ENDLINE INTENT-TO-TREAT EFFECTS ON PARENTS' VISITS TO SCHOOLS AND RELATED OUTCOMES

Notes: This figure plots intent-to-treat effects estimated from (1) for SBAE alone (β_1; hollow circles), SBAE with the promotional video (β_1+β_3; triangles), and SBAE with both the promotional video and the annual farmer field day (β_1+β_2+β_3; squares). Panel A reports indicator outcomes in percentage points; Panel B reports counts. Horizontal bars are 95% confidence intervals based on standard errors clustered at the geographical-cluster level. All outcomes are endline parent reports. Visits are counted for the second rainy season (2022) and parent-teacher meetings for the 2022/23 school year; techniques learned are promoted techniques that parents report having first learned from the school or from students in the past two years. Full estimates, including the overall SBAE effect that pools all SBAE schools, the field day combination (β_1 + β_2) and Lee bounds, are in Online Appendix Table OA14. Significance: *** p<0.01, ** p<0.05, * p<0.10.

assess channels through which parents learn promoted techniques. In the endline survey, after probing parents' awareness of promoted techniques in open-ended questions about planting methods, enumerators follow up by asking when and how they first learned the promoted techniques — in particular, whether they learned it from the SBAE schools, from students specifically, or from other members of the community. These rows examine treatment effects on the number of techniques parents have learned, focusing on reports of learning within the past two years. Two interesting patterns emerge. First, SBAE alone increases parents' learning from both schools (0.114 techniques; 190% rise from control schools) and students (0.081 techniques; 405% from control schools). Second, both the promotional video and the annual farmer field day substantially increase parents' learning from schools, but not from students. Specifically, including both types of parental engagement increases the number of techniques parents learn from schools from 0.174 to 0.714 — an increase by around fourfold. This pattern suggests that parental engagement is particularly important in enabling parents to learn the technical aspect of promoted techniques via visits to schools — a function that is less fulfilled by intra-household interactions.

Students' home projects, communication with parents, and parents' observations. Figure 14 turns to the second diffusion mechanism of SBAE — intra-household interactions between students and parents, with full estimates in Online Appendix Table OA15. Panel A examines whether SBAE leads to increased student home projects, as manifested in various proxies about whether students manage household farms. Its first four rows focus on two measures that are reported by students in the midline and endline surveys: (i) whether students look after farms; (ii) whether students choose planting methods on the student parcel. Two patterns emerge. First, while SBAE has some positive but imprecise effects on these proxies of student-led farms, the promotional video intensifies the process. Specifically, SBAE alone raises the fraction of students who look after farms in the midline and endline — only slightly — to 56.3% (from 53%) and 54.5% (from 48%); with the promotional video, these measures increase to 63.6% and 58.8% respectively. The contrast is even sharper if we focus on the more stringent proxy about student-led farms — whether they choose planting methods on the student parcel. SBAE alone raises this fraction in the midline and endline to 23.9% (from 18%) and 27% (from 23%); with the promotional video, these measures increase to 30.8% and 34.9%.

Besides student-led home projects, students could also influence household technology adoption and educational decisions through their communication with parents and parents' observations. The remaining rows turn to these other mechanisms of intra-household interactions, examining whether parental engagement has encouraged more active communication between students and parents. The fifth row of Panel A examines the fraction of students who have asked parents for permission to change farming practices on household farms, as reported by parents. Both the promotional video and the annual farmer field day significantly increase this fraction. Their collective impact is substantial, increasing this fraction from 41.3% in SBAE-only schools (37% in control schools) to 56.3%.

Panel B examines three measures of communication that are reported in the midline student survey. These questions were asked as follow-ups when students have adopted promoted techniques on the student parcel. The three measures are: the number of techniques (i) that students have shown parents how to make; (ii) that students have shown parents the associated harvests; (iii) that students have advised parents to use on other parcels. Parental engagement substantially raises these measures (i) from 0.26 to 0.52 techniques (0.27 in control schools); (ii) from 0.24 to 0.41 techniques (0.21 in control schools); and (iii) from 0.23 to 0.33 techniques (0.18 in control schools).

Students' home projects, requests to change practices on household farms, and communication with parents can all influence parents' technology adoption via their impact on parents' beliefs about the returns from adoption. The last row of Panel A captures this mechanism by asking endline parents whether they have observed improved root crop harvests on students' parcels in the last two years, where improved root crop harvests is defined as either an increase in the size or number of tubers per plant. Both the promotional video and the annual farmer field day raise this fraction, though only the former's effect is statistically significant

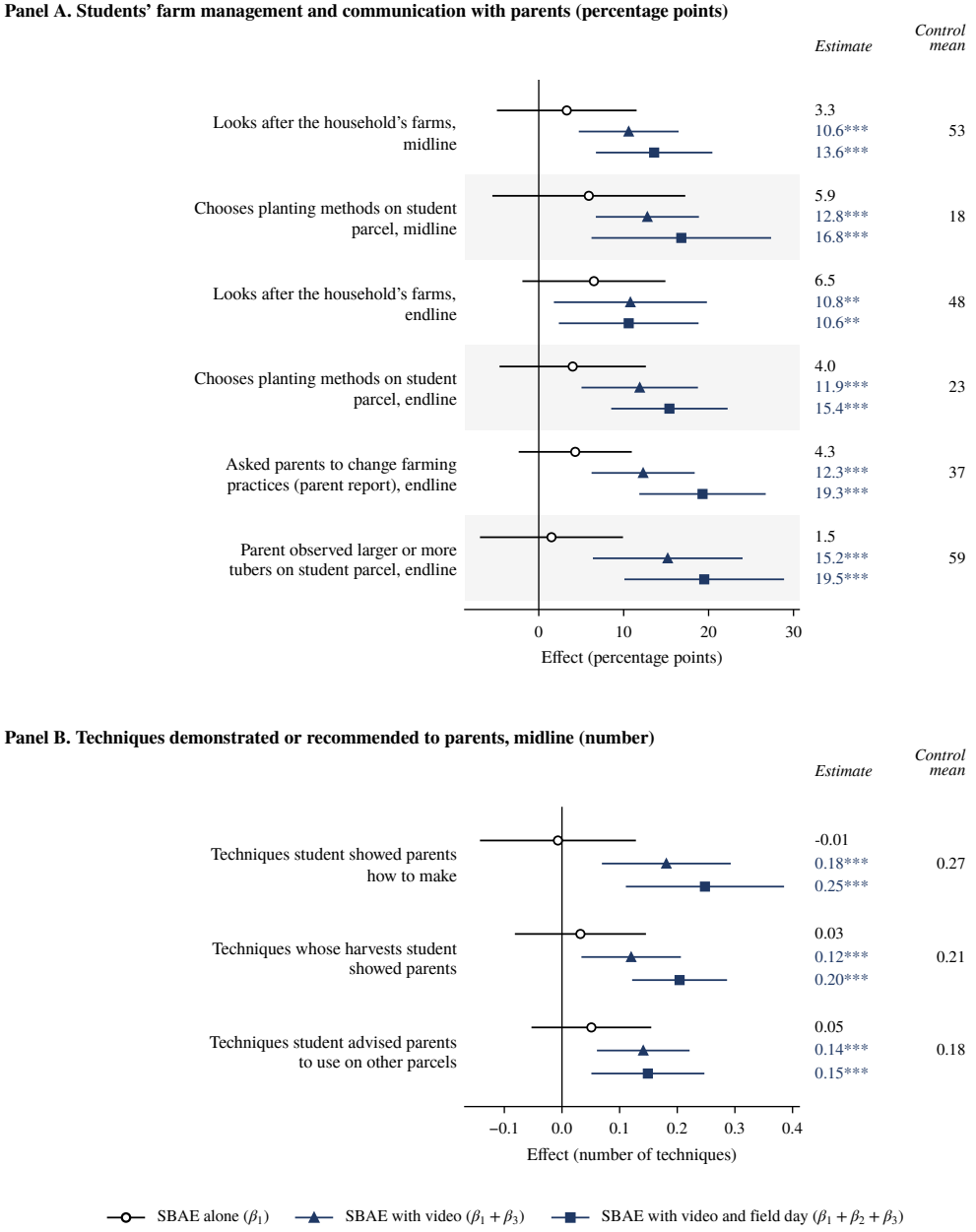


FIGURE 14. MIDLINE AND ENDLINE INTENT-TO-TREAT EFFECTS ON STUDENTS' MANAGEMENT OF HOUSEHOLD FARMS AND RELATED OUTCOMES

Notes: This figure plots intent-to-treat effects estimated from (1) for SBAE alone (β_1; hollow circles), SBAE with the promotional video (β_1+β_3; triangles), and SBAE with both the promotional video and the annual farmer field day (β_1+β_2+β_3; squares). Panel A reports indicator outcomes in percentage points; Panel B reports numbers of promoted techniques. Horizontal bars are 95% confidence intervals based on standard errors clustered at the geographical-cluster level. Looking after farms, choosing planting methods and the three technique counts are student reports; asking parents to change farming practices and observing larger or more tubers on the student's parcel are endline parent reports. "Other parcels" are parcels other than the student's own. Full estimates, including the overall SBAE effect that pools all SBAE schools, the field day combination ($\beta_1 + \beta_2$) and Lee bounds, are in Online Appendix Table OA15. Significance: *** p<0.01, ** p<0.05, * p<0.10.

and it is around three times larger. Their collective impact is substantial — raising the fraction from 60.5% (59% in control schools) to 78.5%.

5.3 SBAE without parental engagement: the β_1 estimates

Figure 15 plots β_1 from (1), the effect of SBAE in schools that received neither engagement treatment, on every primary outcome.

Despite its positive training effects on teachers and students (Section 5.1), SBAE on its own does not improve most of the outcomes it targets. Taking the outcomes in the order of Figure 15: (i) Technology adoption. On the student parcel, SBAE alone has small and statistically insignificant effects on both the use of bed preparation and the number of promoted techniques used, at both midline and endline. On the parent parcel, it has essentially zero effect on the use of bed preparation, although it increases the number of techniques used by 0.2 (14% from 1.38 in control schools). (ii) School attendance. SBAE alone has no effect on dropouts but increases absenteeism by 26.2% in the midline (an increase of 0.18 from 0.69 out of 5 days) and 31.2% in the endline (an increase of 0.2 from 0.65 out of 5 days); both increases survive the Lee bounds. Its effect on total days of attendance is small and statistically insignificant. (iii) Time use. SBAE alone reduces students' weekly studying hours by 10.6% in the midline (a drop of 0.6 hours from 5.69 hours per week) and by 19.9% in the endline (a drop of 1.07 hours from 5.39 hours per week), consistent with the drop in students' studying hours in the first follow-up survey, while leaving farming hours unchanged. (iv) Income and savings. SBAE alone has no significant effect on farm sales, reduces the fraction of students with non-farm income by 6.1 percentage points (13% from 47% in control schools), and has no significant effect on total income or savings. (v) Aspirations. SBAE alone has no significant effect on whether students study agriculture as an elective subject, increases students' naming of agricultural careers by 7.8 percentage points (18% from 43% in control schools), and has no significant effect on whether students save for attending university.

Pooling all SBAE schools masks these standalone effects. The overall SBAE effects, reported in the odd-numbered columns of Online Appendix Tables OA4 to OA10, are positive for technology adoption on both parcels, enrollment, farm sales, the fraction of students with savings, and all three measures of aspirations, and close to zero for absenteeism and studying hours, because they average over SBAE schools with and without parental engagement.

5.4 Summary

I have presented evidence that parental engagement effects are unlikely due to increased student participation or responses to SBAE training in Section 5.1.3. What remains is the possibility that the pivotal effects of parental engagement work outside the school. This is a process of elimination rather than a proof. Section 5.2 presents solid evidence that the dual intra-household mechanisms of SBAE — parents' visits to schools and intra-household interactions between students and parents — are enabled by parental engagement. The SBAE program on its own has only small, and in several cases negative, effects on these mechanisms. Further, each mechanism has distinct effects on parents' exposure to promoted techniques — (i) parents' visits to schools lead to a fourfold increase in parents' learning of promoted techniques from schools; (ii) students' home projects and increased interactions with parents leads to a 13-fold increase in the treatment effect on parents' observations of improved yields on students' parcels. Both channels could contribute to improvements in technology adoption and school attendance via increasing parents' increased acceptance of promoted agricultural techniques.

Parental engagement also has downstream effects on parents' agricultural knowledge and beliefs and on attitudes towards education (Online Appendix Table OA17). On its own, SBAE raises neither parents' score on the test of promoted techniques nor the share who expect students to out-harvest a typical adult farmer; with both engagement treatments, the score rises by 0.35 of a point and the share by 10.5 percentage points.

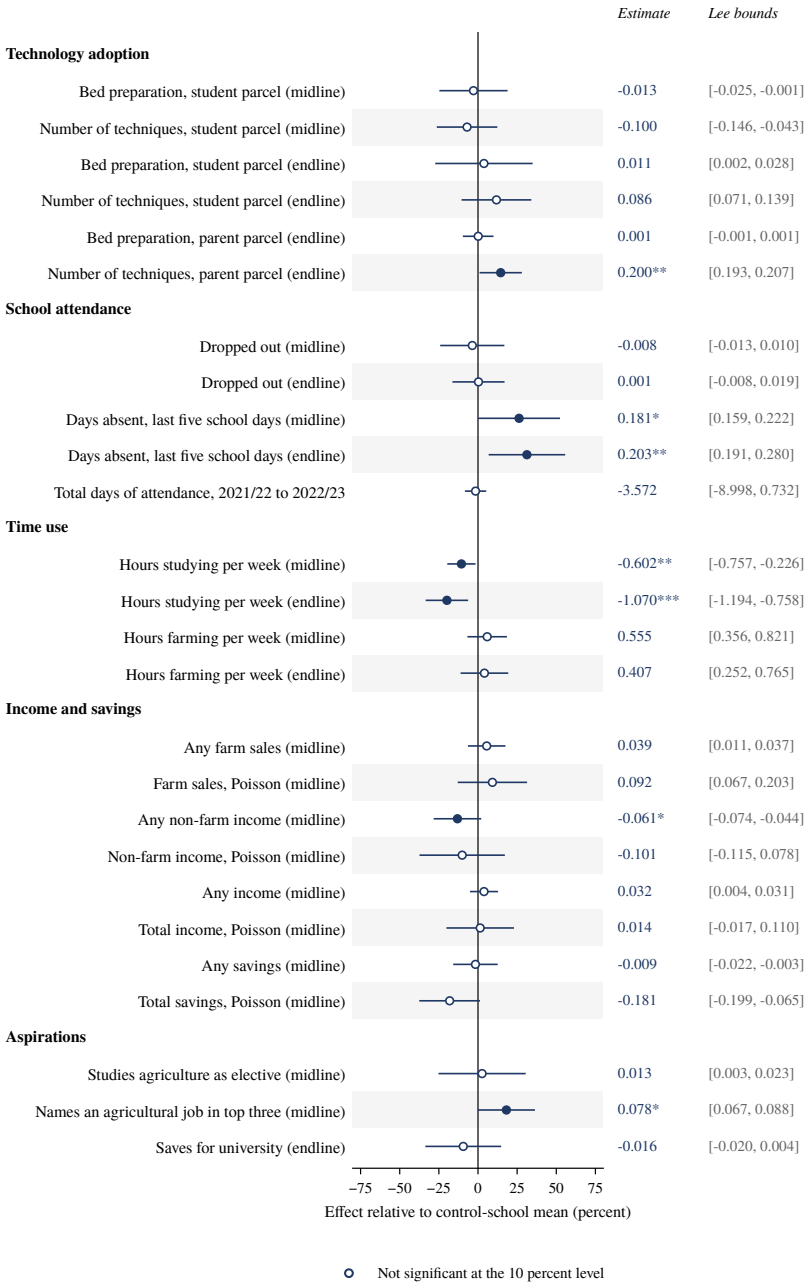


FIGURE 15. SBAE WITHOUT PARENTAL ENGAGEMENT (β_1)

Notes: This figure plots the intent-to-treat effect of SBAE without parental engagement (β_1 in (1)) on each primary outcome. In the left panel, estimates, 95% confidence intervals and Lee bounds (brackets) are divided by the control-school mean; Poisson estimates are proportional changes and are shown without rescaling. Filled markers denote estimates significant at the 10% level. The right panel reports the estimate in original units with its Lee bounds (stars on each bound are based on its own standard error) and the estimate relative to the control-school mean. "Dropped out" is one minus the enrollment indicator, so its estimates and bounds have the opposite sign to those in Online Appendix Table OA6. Standard errors are clustered at the geographical-cluster level. Significance: *** p<0.01, ** p<0.05, * p<0.10. Full estimates are in Online Appendix Tables OA4 to OA10.

The field day also reduces the share of students who missed school in 2022/23 because a household member asked them to work, by 7.5 percentage points from 24% in control schools.

The mechanisms also clarify the division of labor between the two engagement treatments documented in Section 4.3. Both enable the first diffusion channel: parents visiting schools, attending parent-teacher meetings, learning promoted techniques, and observing harvests on school farms. Only the promotional video enables the second: students starting home projects and parents observing improved yields on household farms. This difference is consistent with the pattern that parents' technology adoption, students' farm sales, and dropouts respond only when the video is included, while the field day's distinct contribution is to reduce household requests for students' labor, which lowers absenteeism. Appendix C documents these marginal effects on each mechanism.

6 A puzzle and its interpretation

6.1 The puzzle

SBAE aims to break the cycle in which low agricultural productivity and household labor needs depress school attendance. It works through two channels: school farms that demonstrate improved techniques to parents, and student home projects that test those techniques on the household's own soils. The parental engagement treatments center on a promotional video that explains how SBAE differs from typical school gardens, which merely employ students as farm assistants. Taken together, the results in Sections 4 to 5 have five features that any explanation of parents' responses needs to account for at the same time.

F1. A reversal in sign. Without parental engagement, SBAE fails to raise adoption of the main yield-improving technique on any household parcel, increases absenteeism, and reduces students' studying hours (Section 5.3). With engagement, SBAE is among the most cost-effective agricultural extension programs evaluated in Africa in diffusing technology, and it is 1.7 to 2.5 times as cost-effective as conditional cash transfers in raising school attendance (Section 4.2 and Section 4.4).

F2. Avoidance of cheap, available information. Over the three years of the trial, 81% of students in schools without parental engagement joined the program, yet only 44% of their parents visited the school farms. Without the informational treatment, SBAE does not increase the number of parents' visits to school farms in the second rainy season, and it reduces the number of parent-teacher meetings that parents attend by 39% relative to control schools (Section 5.2).

F3. A low-content trigger with a lasting response. A one-time promotional video centered on a video was enough to change the sign of the program's effects, and the reversal persisted until the endline survey.

F4. Breadth. Parents' responses are not limited to their engagement with the program. They also extend to their children's studying hours and school attendance.

F5. Same evidence, opposite responses. Parents in SBAE schools with and without parental engagement face the same underlying program and the same opportunities to gather evidence about it, while parents in control schools received no program at all.

6.2 What the standard explanations leave unexplained

Bayesian updating under a single prior. Visiting the school farm takes some time and effort, but the cost is modest: most households live within walking distance of the school. Consider first a parent who receives a neutral signal about the program. If her prior about the program's value is sufficiently diffuse, the information gained from a visit should be worth this cost, and she should visit more often as the program unfolds rather

than less often; at the very least, she should maintain the visit frequency of parents in control schools rather than fall below it (F2). For visits to fall, parents' prior beliefs must be concentrated enough that what they observe of SBAE is taken as confirming their existing view. A concentrated prior can still be overturned by a sufficiently informative signal, so the reversal is not by itself a contradiction. What the account must then supply is a reason why a single video with little technical content was informative enough to overturn that prior, and to keep it overturned for two years, while parents' own cheaper opportunities to investigate the program were not (F3). Moreover, the content of the news does not by itself determine whether it is good or bad. The main signal that parents in SBAE-only schools receive is their children's report that part of the school day is spent on a farm. This report is bad news if the program is seen as a typical school garden, but good news if it is seen as training in farm management (F1, F5). Whether parents treat the report as good or bad news therefore depends on how they interpret the program, rather than on the report itself.

Bayesian updating after a negative signal. Consider next a parent who holds a diffuse prior but receives a negative signal about the program's value because she perceives SBAE as a typical school garden that uses students only for chores. With a fixed cost of visiting, there is a range of beliefs in which acquiring further information is not worthwhile. A sufficiently precise negative signal would move her into this range, after which she would stop checking on the program. The informational treatment would move her out of this range, and her own subsequent learning would sustain the change. Under this account, the video does not need to do all of the persuading by itself, so neither the size of the reversal nor its persistence is, on its own, evidence against Bayesian updating (F2, F3). This is the strongest alternative to the interpretation I propose below. However, three features of the setting are difficult to reconcile with it.

First, parents in control schools received no program. The account therefore requires parents in SBAE schools to conclude that a school that received a farm, teacher training, and materials is less worth engaging with than a school that received nothing (F5). Second, the negative signal would need to be misleading, and misleading in the same direction for many parents. SBAE has positive training effects on teachers and students in all three years and across all arms (Section 5.1), and parents in both arms face the same underlying program and the same opportunities to gather evidence about it, which in schools with parental engagement is favorable enough to sustain the reversal. For the signal to have driven parents in schools without engagement away from the program, it must therefore have misled them systematically and persistently. Since the evidence that parents could gather for themselves is the same across arms, this can happen only if parents stop looking, which is the behavior to be explained (F2, F5). Third, the response is broader than this account predicts. A signal about the quality of one program should change parents' engagement with that program, but it does not explain why children's studying hours and school attendance fall (F4).

An imprecise negative signal does not rescue the account either. With a single prior, the value of a visit depends on how uncertain the parent remains, not on how negative the news was. An imprecise signal leaves the parent more uncertain, and therefore raises the value of visiting (F2). Two qualifications apply. First, if the returns to SBAE depend on how many parents engage with the program, a parent's unfavorable reading may be correct rather than mistaken, and the treatment may coordinate parents on a better outcome. This hypothesis implies that the effects on a parent should depend on how many other parents at the same school were treated. Second, no reduced-form comparison can rule out every explanation that works through the level of beliefs, because any response can be rationalized by some unobserved belief content. Distinguishing these accounts requires variation in how the program is presented while holding the information provided fixed, which I plan to pursue in future work.

Selective attention. In models of selective attention, people fail to learn because they do not notice dimensions that they believe to be irrelevant, and pointing out those dimensions restores learning (Schwartzstein, 2014; Hanna et al., 2014). Applied to this setting, the account implies that parents are unaware of the program's science instruction, the new techniques, or students' home projects, and that pointing these out would restore learning. The two engagement treatments provide a test. The annual farmer field day directs parents'

attention to precisely these features on the school farm and carries more technical content than the video, yet it leaves dropouts and parents' technology adoption unchanged, whereas the video does not (Appendix C). Fieldwork points the same way: parents are aware of these features, but they lack a way of interpreting them under which agriculture and education reinforce each other. Inattention also explains a failure to learn, not an active withdrawal; parents in SBAE-only schools attend fewer parent-teacher meetings than parents in control schools and reduce their children's schooling (F2, F4). Nor does the account explain why the same facts are read as bad news in one arm and as good news in the other (F5).

Associative memory. Models of associative memory explain why a cue retrieves past experiences that resemble it (Bordalo et al., 2020, 2022, 2026). These models account well for parents' initial reading of the program. A farm at a school evokes familiar school gardens, which are widely associated across Africa with drudgery that trains students to be obedient farm assistants (Lowe, 1986; FAO, 2010). The models also allow a different cue to retrieve a different category, which fits the immediate effect of the video (F1, F5). However, they do not describe how people search for information. Because they select one representation at a time and abstract from information acquisition, they cannot explain why parents avoid cheap information that would resolve their uncertainty (F2); a parent who retrieves unfavorable memories can still recognize that her reading of the program is uncertain.

6.3 An integrative explanation

The interpretation I favor is that parental engagement shifts parents from viewing agriculture and education as substitutes to viewing them as complements. Without engagement, parents interpret the program through a familiar, precise, and widely shared default view. This view rests on several preconceptions: that school gardens train obedient farm assistants rather than building agribusiness skills; that farming is what children fall back on when schooling fails, so that education is the route out of agriculture; and that hours spent on a farm are hours taken away from learning. Under this view, a program that trains children in farming raises the relative return to using them as farm labor rather than keeping them in class, which explains why absenteeism rises and studying hours fall without engagement while dropouts are unaffected (F1, F4). Children's reports that school time is spent farming confirm the view (F5), and engaging with the program appears pointless (F2). This is better described as an aspirations failure than as a pure information friction of the kind studied by Jensen (2010), Bergman (2021), and Dizon-Ross (2019). In those settings, parents lack important facts about returns to education or their children's performance. In this setting, parents have access to the relevant facts about SBAE, but they lack an interpretation of the program under which these facts are valuable.

The alternative interpretation treats the school farm as applied science. Under this interpretation, farm management skills raise the returns to both schooling and farming, and students' home projects test the promoted techniques on the household's own plots. This interpretation cannot be confirmed by any single observation. For SBAE to pay off, the program must be implemented well, its funding must continue after donor support ends, the techniques must suit local soils, students must acquire management skills rather than simply perform tasks, and teachers must change how they teach. Whether these conditions hold becomes clear only through personal and repeated observations that unfold over time, such as visiting the school farm at different times or assigning students a trial plot and watching the results. Gathering such evidence takes time and resources, and keeping track of an unfamiliar reading takes mental effort. When past experience, such as students serving only as farm assistants in their communities, makes parents confident in the default view, such evidence promises too little to justify these costs.

The video works in two ways beyond supplying facts. First, it provides evidence that is hard to reconcile with the default view, such as town chiefs' testimony about previous participants' management skills and transformed livelihoods. Second, by explaining how the agricultural and educational components of 4-H interact, alongside endorsements by government officials and teachers, it makes the complements reading worth entertaining. The video does not settle the matter, but it gives parents a reason to look. Parents then

visit and learn from school farms, assign plots to students for home projects, and discuss the new techniques within the household. Without engagement, parents hold only the default reading and have no reason to question it, so they see little value in visiting the school.

This account has a counterpart in the neuroscience of cognitive maps, which describes how the brain represents a situation (O'Keefe and Dostrovsky, 1971; O'Keefe and Nadel, 1978; Hafting et al., 2005). For a familiar context the brain settles on one well-learned map, and that map behaves like an attractor that snaps back after a brief disturbance (Wills et al., 2005; Jezek et al., 2011), which is what a default reading of a school farm looks like. Exposure to a new environment selects among maps the animal already has rather than installing a new one (Dragoi and Tonegawa, 2011), so a treatment determines which reading is active, not which readings exist. Which map becomes active tracks the evidence in the way Bayesian inference over contexts would (Sanders et al., 2020).

The explanation is therefore integrative rather than a rival to the accounts in Section 6.2. Associative memory accounts for the default: a farm at a school retrieves the familiar school garden. Bayesian updating governs the shift: the engagement treatments move weight toward the complements reading in proportion to how well it fits what parents can see. Attention remains selective, but across readings of the program rather than across features within one, which is why the field day, aimed at features, does not move adoption while the video does. A companion paper (Lee, 2026b) develops this formally, with parents weighing competing readings of a situation and gathering evidence only about the readings they take seriously.

Several pieces of suggestive evidence support this account. First, the video shifts parents' beliefs about students' farming abilities: 97% anticipate growth in students' farm management abilities within a year, the share expecting students to harvest more than typical adult farmers in the community rises from 31% to 70% immediately after viewing, and the randomly assigned version that adds testimonials moves beliefs significantly more than the version with the explanation alone. Beliefs about students' cassava yields also remain significantly more optimistic at both midline and endline than those of parents in schools without videos (Online Appendix C). Second, among parents who watched the video, and conditional on the version they saw, these post-video beliefs in turn predict the search that follows: their subsequent visits to school farms, their ability to name field officers, and their attendance at parent-teacher meetings. Third, the annual farmer field day provides more technical content than the video, yet only the video activates students' home projects and intra-household diffusion, raises parents' technology adoption, and reduces dropouts (Appendix C, Figures C1 and C2). The first and third comparisons are randomized; the second is an association among parents who all watched a video, so I read it as evidence that the belief measures carry content rather than as a mediation channel. These measures concern students' expected harvests and farm management ability, which are observable implications of the interpretation parents hold rather than direct measures of it.

These findings are, of course, suggestive. In the companion paper (Lee, 2026b), I derive observable implications that distinguish this new theory from standard Bayesian and behavioral models.

7 Concluding remarks

Finding an effective delivery model for agricultural extension stands out as one of the foremost challenges in African rural development. Using a randomized experiment with 197 schools, this paper provides proof of concept that schools can be a promising entry point for diffusing yield-improving agricultural technologies. This promise lies in two parts. First, I show that — contrary to concerns about pitfalls — with appropriate implementation, school-based agricultural education can in fact encourage school attendance alongside increasing households' technology adoption. This qualifies the conventional view that agriculture and education compete for a child's time. Lee and Udry (2026) formalize this by augmenting the standard target-input model of how a rural household learns about a new technology's suitability: schooling enters the learning technology, so time in school and technology adoption reinforce one another. Second, due to scale economies

in leveraging the school infrastructure, the program offers both cost-effectiveness and scope of impact. Per $100 spent, it induces at least as many households to adopt new techniques as nearly every other extension program in Africa evaluated by randomized trial, and for the increase in total days of attendance it is 1.7 to 2.5 times as cost-effective as a well-cited conditional cash transfer benchmark in Malawi (Baird et al., 2011). In addition, the program raises students' savings and their aspirations for higher education, without increasing their farming hours or reducing household consumption.

Alongside the promise of school-based agricultural education, it should be noted that these large, positive effects are achieved only when parental engagement is included. To the extent that school-based development programs have strategic advantages in logistics (e.g. scalability and sustainability), this result offers two general lessons. First, we should conduct joint evaluations of school-based development programs and household interventions, as this paper reveals that the former could have hidden potentials that are only unlocked with the latter. Second, we should investigate ways to enhance students' agency in amplifying the impact of school programs, not just as a matter of youth empowerment, but as ways to increase the cost-effectiveness of school programs.

How parents responded carries a further lesson. Without engagement, parents forgo cheap information about a program their children have joined, and a single video reverses the program's effects for two years. Bayesian updating under a single prior, selective attention, and associative memory each fall short on their own. I argue instead that parents interpret SBAE through a familiar default view, in which schooling and farm work are substitutes, and that the engagement treatments work by making an alternative view worth looking into rather than by supplying facts. Development programs can therefore fail not because facts are missing, but because their innovative features are misinterpreted.

Beyond immediate impacts, this paper demonstrates that schools can serve as sustainable rural development hubs when coupled with low-cost parental engagement events. The first step is to motivate students to attend schools, triggering a virtuous cycle in which schools are strengthened through improved incomes and provide higher-quality education. However, while the current RCT demonstrates positive effects on technology adoption and school attendance, it shows no improvements in students' academic performance or agribusiness knowledge. The second step, therefore, is to synergize SBAE with complementary interventions. One direction that I am taking is to integrate the highly effective, student-centered "Learning to Learn (LTL)" pedagogy into SBAE, which is shown in a randomized trial in Uganda by Nourani et al. (2025) to be amongst the top 5% education interventions in terms of learning-adjusted years of schooling. While complementary with the student-centered, inquiry-based instruction promoted by SBAE, this intervention does not prescribe fixed teaching methods. Instead LTL prompts teachers to reflect on how they learn, emphasizing active learning, critical thinking, and problem-solving skills essential for students to effectively apply agricultural knowledge in real-world contexts. Another direction is to link SBAE to home-grown school-feeding programs, creating direct market demand for students' agricultural produce while expanding the scope of agribusiness education. A third direction is to leverage the routine student data collection system developed during the RCT to conduct iterated randomized trials on different agricultural technologies. This approach is particularly promising when combined with algorithmic farming advice, a partnership currently under development.

As of writing, the current randomized trial has significant policy impact in sub-Saharan Africa, scaling to all rural schools in Liberia by 2035, with expansion to Côte d'Ivoire and Kenya beginning in 2026. In the long term, this holistic approach of SBAE can contribute to our understanding of macroeconomic development in agrarian economies. First, it addresses whether schools can simultaneously promote rural livelihoods while equipping students with adaptable skills for structural transformation toward higher-value sectors. Second, it contributes to our ability to understand and shape the direction of technical change through a system of routine feedback and enhanced data collection.

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A Attrition

Appendix Figure A1 traces the flow of schools, students, and parents from allocation to analysis, following the CONSORT guideline for cluster-randomized trials. Appendix Table A1 reports attrition rates of students (midline and endline) and parents (endline) by treatment arm, and the reasons for attrition. Section 3.5 discusses the patterns; Online Appendix Table OA3 shows that selection into the surveyed samples does not differ across arms.

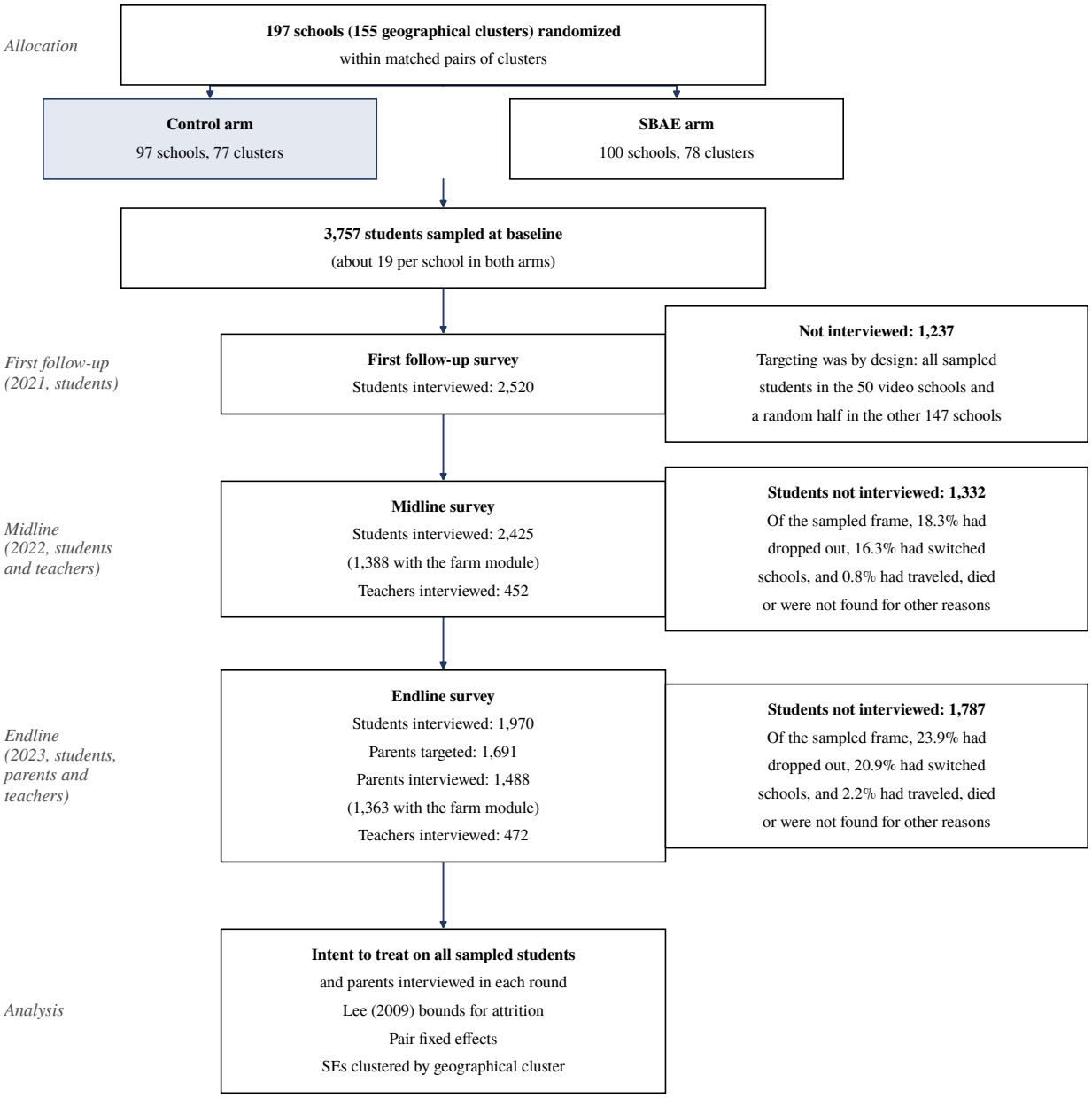


FIGURE A1. PARTICIPANT FLOW

Notes: This figure follows the CONSORT reporting guideline for cluster-randomized trials. Allocation was at the cluster level within matched pairs; all 197 schools remained in their assigned arm and no cluster was lost. Student counts refer to the 3,757 students sampled at baseline (Section 3.3); "not interviewed" lists the reasons recorded by the survey teams, which are the attrition categories in Appendix Table A1. The first follow-up targeted all sampled students in the 50 video schools and a random half elsewhere, so its non-interviews are by design and not attrition. Parents were surveyed at endline only, in a random 45 percent of households stratified by school. Teachers are repeated cross-sections and are not followed. Counts are pooled across arms; Appendix Table A1 reports attrition rates and reasons separately by arm.

TABLE A1—BALANCE IN ATTRITION RATES ACROSS TREATMENT ARMS

Panel A: Balance in attrition

	Midline Students Attrited (0/1)	Endline Students Attrited (0/1)	Endline Parents Attrited (0/1)
$SBAE_p$	0.020	0.028	0.042**
Standard errors	(0.035)	(0.034)	(0.020)
$SBAE_p \times Video_s$	-0.073**	-0.092***	0.017
Standard errors	(0.034)	(0.030)	(0.020)
$SBAE_p \times FFD_s$	0.001	0.046	-0.040**
Standard errors	(0.036)	(0.037)	(0.020)
Control Mean	0.36	0.48	0.09
Overall Mean	0.35	0.48	0.12
Observations	3757	3757	1691
Number of clusters	155	155	155

Panel B: Reasons for attrition

Dropped out or switched schools	Dropped out or switched schools	Traveled
34.9%	45.5%	4.6%
— Confirmed dropped out	— Confirmed dropped out	Relocated
18.3%	23.9%	4.3%
— Confirmed switched schools	— Confirmed switched schools	Working
16.3%	20.9%	1.1%
Traveled	Traveled	Sick
0.2%	0.6%	0.9%
Moved to foreign countries	Moved to foreign countries	Moved to foreign countries
0.1%	0.5%	0.2%
Passed away	Passed away	Passed away
0.1%	0.2%	0.9%
Other reasons	Other reasons	Other reasons
0.4%	0.9%	0.4%

Panel C: Balance in major attrition reasons

	Dropped out or switched schools (0/1)	Dropped out or switched schools (0/1)	Traveled or relocated (0/1)
$SBAE_p$	-0.000	0.024	0.038*
Standard errors	(0.033)	(0.033)	(0.021)
$SBAE_p \times Video_s$	-0.061*	-0.099***	0.014
Standard errors	(0.034)	(0.031)	(0.023)
$SBAE_p \times FFD_s$	0.014	0.046	-0.047**
Standard errors	(0.035)	(0.037)	(0.020)

Notes: This table shows a test of balance for the attrition rates among students and parents in the midline and endline surveys. Panel A regresses a binary indicator of attrition on a binary indicator of the SBAE treatment, an interaction term between the SBAE treatment and the promotional video treatment, and an interaction term between the SBAE treatment and the annual farmer field day treatment. Panel B shows the distributions of reasons for attrition in each survey. Panel C repeats the balance test in Panel A, but using only attrition due to major reasons. All regressions include pair-of-clusters-of-schools fixed effects and a binary indicator of faith-based schools. Standard errors are clustered at the cluster-of-schools level.

B Cost-benefit and cost-effectiveness analyses

This appendix details the assumptions and results summarized in Section 4.4.

Assumptions.

Appendix Table B1 lists all key assumptions in the cost-benefit and cost-effectiveness analyses. I first define the program beneficiaries. Corresponding to the randomized trial, I consider a three-year period in which three cohorts of students in 100 SBAE schools are targeted. Since sampled students represent a random 30% of students in targeted grades, the program reaches roughly 65 students per school in each cohort—a total of 19,500 students across all cohorts and schools. For the analysis of technology adoption, which may include spillovers of farming practices to non-parent households, it is important to note that approximately 410,000 people reside within 2 kilometers of the SBAE schools (LISGIS, 2008).

The total cost over this three-year period is $801,139 (2023 US dollars), or about $40 per student. This covers two components: program implementation ($621,139), including training extension officers and teachers, monthly school monitoring, setting up school farms, and hosting national events for extracurricular clubs; and parental engagement ($180,000), including a promotional video for one parent per student and an annual farmer field day.

An important consideration for program sustainability is the potential for drastically lower costs after the initial three years. Setup costs are not repeated, and I assume monitoring visits are sharply curtailed to once a year, reducing three-year implementation costs from $621,139 to $120,000—a 63% drop in total costs.

Turning to the side of program benefits, the first important component is the increase in students' savings — Section 4.2 shows that in the second year of the program, there is a 21% increase in annual savings from a base level of $20 (2022 US dollars) for students who have not dropped out from schools. I assume that this increase carries over to the third year.

The second important component is the increase in students' school attendance — due to both reduced dropouts and reduced absenteeism. To combine effects on both dropouts and absenteeism, I focus on the treatment effect on the imputed total number of days in attendance, which is 17.6 according to Online Appendix Table OA6.

For the cost-benefit analysis, we must monetize this increase in school attendance. Adopting a conservative approach, we assume an 8% annual return to schooling, implying a return of 0.04% per school day (based on approximately 200 school days per year).[16] Applying a 10% discount rate and assuming that students work for 30 years, we estimate that each additional school day generates $1.89 in discounted lifetime earnings.

The third component, which is also the most uncertain component, is parents' benefits from technology adoption. To calculate these benefits as conservatively as possible, I consider only adoption of bed preparation in one season (only in verified third year) and in 1/4 of the typical cultivated area of roots and vegetables. This tends to understate the benefits as (i) SBAE also increases joint adoption of multiple techniques (as we discuss in Section 4.2.1) tend further raise yields; (ii) parents who experience improved yields tend to continue using the technologies. Further, as yields in the general population are often found to be lower than in agronomic trials, I assume only half of the yield gains in agronomic trials. I use cassava and sweet potatoes as the representative crops (each comprising half of the area of adoption) — these crops are widely grown by Liberian farmers as their flexible use helps satisfy subsistence needs, but have lower prices in the market than other root crops and vegetables. I also consider the potential increase in labor costs due to constructing beds

[16] The global average return to an additional year of schooling is approximately 8.8% (Psacharopoulos and Patrinos, 2018). We use 8% as a conservative estimate. Returns in sub-Saharan Africa, especially at the secondary level, are typically higher, ranging from 10–13% (Montenegro and Patrinos, 2014). A World Bank document (World Bank, 2019) also reports that based on household survey data in 2016, individuals who completed senior high school earned on average 18 percent more than those who completed only junior high school, though this descriptive finding reflects correlation rather than causal returns. Downward revision from these optimistic estimates is reasonable, as standard Mincerian estimates may overstate returns for rural populations who are more likely to remain in the agricultural or informal sector, where credential-based wage premiums are less pronounced.

— 150 hours per hectare. Taking all factors into account, I calculate that each adoption of bed preparation creates a net production value of $64.6.

Cost-benefit analysis.

We distinguish between two types of analysis: first, whether benefits justify costs in the first three years, with known data and the assumptions above; second, whether SBAE is a good long-term investment, viewing from the perspective of a policymaker who commits a stream of spending on SBAE.

Appendix Figure B1 presents the benefits and costs over the first three years, revealing two key observations. First, benefits exceed costs during this period, yielding a benefit-cost ratio of 1.33. Second, even when excluding benefits from parents' technology adoption—a conservative approach for those skeptical about the magnitude of yield gains—the benefit-cost ratio remains at 0.98. In other words, the benefits accruing to students alone nearly justify the program, even under the most pessimistic assumptions regarding parents' gains from technology adoption and potential spillovers of improved farming practices to non-parent farmers.

Appendix Figure B1 demonstrates that the augmented SBAE program is economically justified in the short term. However, this analysis overlooks a key strength of SBAE: its emphasis on capacity building means the program can be sustained through periodic teacher training alone, without ongoing monitoring visits from extension officers. This raises a critical question: what are the long-term returns on SBAE? The answer hinges on two competing considerations. On the one hand, costs drop substantially after the initial three years—setup costs are not repeated, and monitoring visits are curtailed to once a year while teacher training is retained, reducing implementation costs from $621,139 to $120,000, a 63% reduction (inclusive of parental engagement). On the other hand, the key uncertainty is whether the program remains equally effective once external support is scaled back.

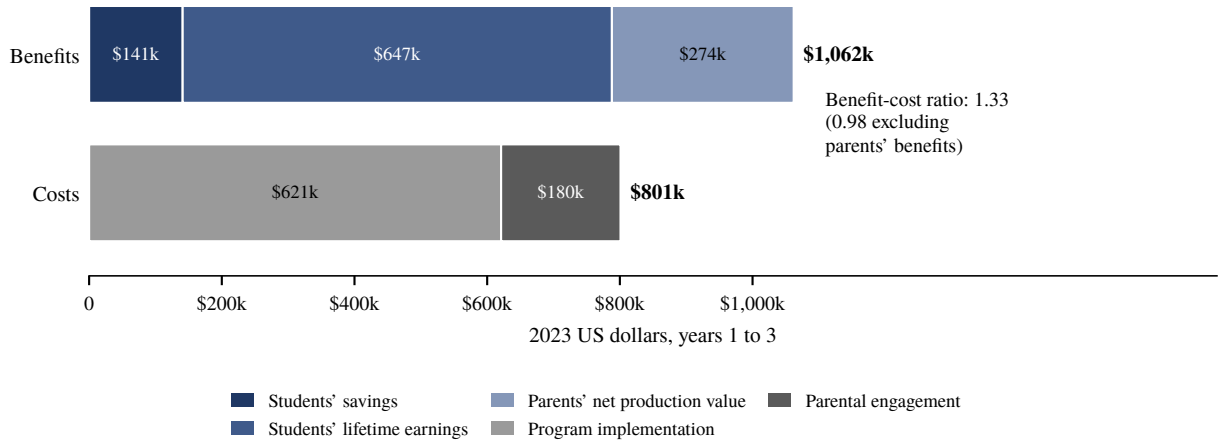


FIGURE B1. BENEFITS AND COSTS IN THE FIRST 3 YEARS OF THE AUGMENTED SBAE PROGRAM

Notes: This figure plots all components of benefits and costs of the augmented SBAE program in the three-year RCT period, in thousands of 2023 US dollars. Students' lifetime earnings are discounted to present value. The benefit-cost ratio divides total benefits by total costs; excluding parents' net production value, it is 0.98. Assumptions are listed in Appendix Table B1.

Appendix Figure B2 presents the 10-year cost-benefit analysis under two scenarios. During the initial three-year implementation period, the benefit-cost ratio is 1.33. In Panel A, which assumes program benefits remain unchanged after the first three years, the benefit-cost ratio for Years 4–10 rises to 3.54, yielding a cumulative benefit-cost ratio of 2.36 over the ten-year horizon. In Panel B, which assumes a more conservative scenario where program benefits decline to 50% after the first three years, the benefit-cost ratio for Years 4–10 is 1.77, with a cumulative benefit-cost ratio of 1.53 over the ten-year period. While Panel A highlights

TABLE B1—KEY ASSUMPTIONS AND PARAMETER VALUES

Item	Value	Justification
Scope & reach		
Period of consideration	3 years	RCT period
Number of schools	100	Schools in SBAE arm
Direct beneficiaries (households)	19,500	3 cohorts × 6,500 students
Community population (within 2 km of schools)	410,000	2008 census data
Cost assumptions (Years 1–3)		
Total cost	\$801,139	
Program cost	\$621,139	Training of extension officers and teachers, monitoring costs, setup costs
Parental engagement cost	\$180,000	Promotional video to every cohort and annual farmer field day
Cost assumptions (Years 4–6 and beyond)		
Total cost	\$300,000	
Program cost	\$120,000	Dropping setup costs; monitoring visits curtailed to once a year
Parental engagement cost	\$180,000	Same as before
Students' savings		
Base annual savings per student	\$21	Average in control schools (translated into 2023 US dollars)
Growth rate of savings	21%	RCT finding on Year 2: Section 4.2.3
Savings increase (Year 2) for non-dropouts	4.41	92% increase
Savings increase (Year 3) for non-dropouts	4.41	Assuming saving increase in Year 2 carries over
Students' discounted lifetime earnings		
Number of additional school days per student	17.6	RCT finding: Section 4.2.2
Base annual income	\$500	Typical annual income in rural Liberia
Return on additional school day	8/200%	Implying annualized return of 8%
Discount rate	10%	Standard rate in program evaluation
Present value per extra school day	\$1.89	Working for 30 years after finishing school
Parents' benefits from adopting bed preparation		
Number of parents adopting	4,251	RCT finding: 19,500 households × 2 parents × 10.9%
Cassava base yield (kg/ha)	8,280	FAOSTAT database
Cassava yield increase	15%	1/2 of the 30% yield gain in agronomic trial
Sweet potato base yield (kg/ha)	1,283.4	FAOSTAT database
Sweet potato yield increase	35%	1/2 of the 70% yield gain in agronomic trial
Adoption area per household (ha)	0.15	1/4 of typical cultivated area for roots and vegetables
Labor increase (hrs/ha)	150	Estimates from FAO guidebooks
Cassava price (USD/kg)	\$0.21	Average market price in 2023 from FAO
Sweet potato price (USD/kg)	\$0.30	Average market price in 2023 from FAO
Labor cost (USD/hour)	\$0.43	Agricultural wage rate in rural Liberia
Net increase in production value per adoption	\$64.60	Increased production value net of increased labor cost

Notes: This table lists all essential assumptions used for cost-benefit and cost-effectiveness analyses in Section 4.4 and this appendix. All monetary values are expressed in 2023 US dollars.

SBAE's potential to deliver even higher returns over time, the results in Panel B provide a robustness check that strongly justifies long-term policy commitment. By capitalizing on the institutional capacity and teacher training established during the initial implementation period, sustained returns can be achieved at a fraction of the initial costs.

Cost-effectiveness analysis.

We now compare SBAE's cost-effectiveness in addressing the dual challenges of diffusing agricultural technologies and increasing school attendance against major alternatives in sub-Saharan Africa, drawing on randomized trial evidence from Innovations for Poverty Action. The Online Appendix provides further details on these programs and cost-effectiveness calculations.

Appendix Figure B3 compares the impact per $100 of the augmented SBAE program with other African programs evaluated using randomized trials. I first assess SBAE's cost-effectiveness in increasing technology adoption by calculating the number of households that adopt promoted techniques per $100 invested. For SBAE, I measure adoption of bed preparation on parents' parcels at endline. A key unknown—which I will track in a 2026 follow-up survey—is the adoption rate among randomly sampled non-parent farmers in nearby communities. I assume this rate (for communities within 2 kilometers of schools) ranges from 0% to 5%, in line with estimates of positive spillovers in farming practices from the social learning literature.

The prevailing mode of agricultural extension in developing countries is the contact farmer model, in which extension agents train selected village farmers who are then expected to disseminate practices to their peers. As Suri and Udry (2022) summarize, this approach has generally proven ineffective at triggering adoption beyond direct trainees. Efforts to improve extension have largely focused on enhancing this existing model—by tweaking how contact farmers are trained, leveraging information technologies to deliver messages to farmers, or increasing social learning by choosing contact farmers more carefully. I compare SBAE, which represents a departure from the contact farmer approach, against these RCT-evaluated programs. Despite differences in the specific techniques promoted, all programs target soil management—a pervasive agronomic problem—making them reasonably comparable.

Appendix Figure B3 shows that, with the exception of BenYishay and Mobarak (2019), SBAE's impact per $100—0.46 to 0.94 households adopting bed preparation, or 0.55 to 1.02 households adopting bed preparation *and* a complementary soil management technique—far exceeds that of extension programs using the contact farmer model. Kondylis et al. (2017) attempt to address imperfect implementation and accountability among extension agents by adding a centralized training workshop for contact farmers. While this increases adoption among contact farmers, it fails to reach untrained farmers, yielding an impact of just 0.11 households adopting pit planting per $100. Two other notable studies evaluate the use of farmer field days and video messaging. These interventions are similar in cost to the annual farmer field day and promotional video I introduce as parental engagement treatments in SBAE, but differ in that agricultural training targets adults rather than students. Fabregas et al. (2023) study the effects of farmer field days in promoting Mavuno fertilizer adoption. With an intent-to-treat effect of 4 percentage points and 100 to 300 farmers reached per field day, the impact is 0.15 to 0.46 households per $100. Van Campenhout et al. (2021) evaluate video-mediated extension messages designed to teach optimal crop spacing to maize farmers in Uganda. This technique is comparable to bed preparation in the present study, as both are relatively easy to adopt. Despite encouraging effects on knowledge, practices, and yields, the program induces only 0.62 households to adopt per $100 spent, placing it at the lower end of SBAE's cost-effectiveness range. The only program that outperforms SBAE is village-based extension in Malawi augmented with performance incentives for contact farmers (BenYishay and Mobarak, 2019)—and only when the outcome is composting adoption (1.53 households per $100). When considering pit planting, a technique more comparable to bed preparation given similar labor intensity and complexity, the impact falls to 0.6 households per $100, within the lower half of SBAE's range.

Second, I assess SBAE's cost-effectiveness in increasing school attendance by calculating additional school days per student per $100 invested. I benchmark against conditional cash transfers (CCTs), one of

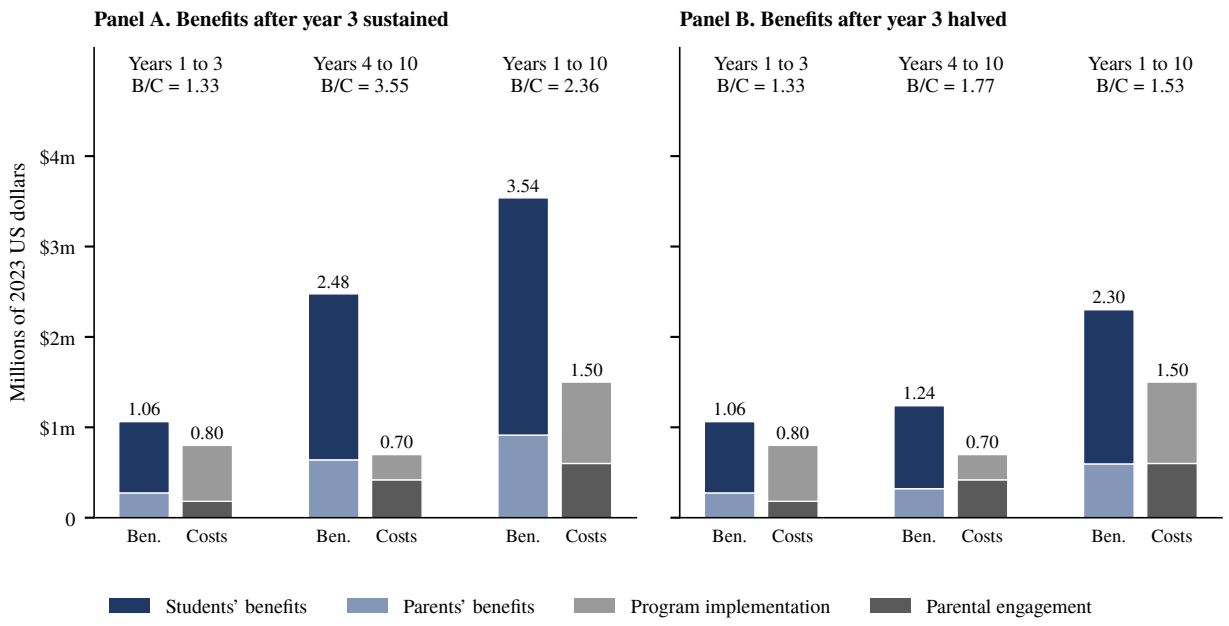


FIGURE B2. SBAE'S BENEFIT-COST RATIOS UNDER DIFFERENT ASSUMPTIONS ABOUT POST-RCT PROGRAM EFFECTIVENESS

Notes: Years 1–3 are as in Appendix Figure B1. For each of Years 4–10, benefits equal the average annual benefit in Years 1–3 (Panel A) or half of it (Panel B), and costs are $40,000 for program implementation (teacher training and annual monitoring visits) and $60,000 for parental engagement. Numbers above the bars are totals in millions of 2023 US dollars; amounts across years are summed without further discounting. B/C is the benefit-cost ratio for each period.

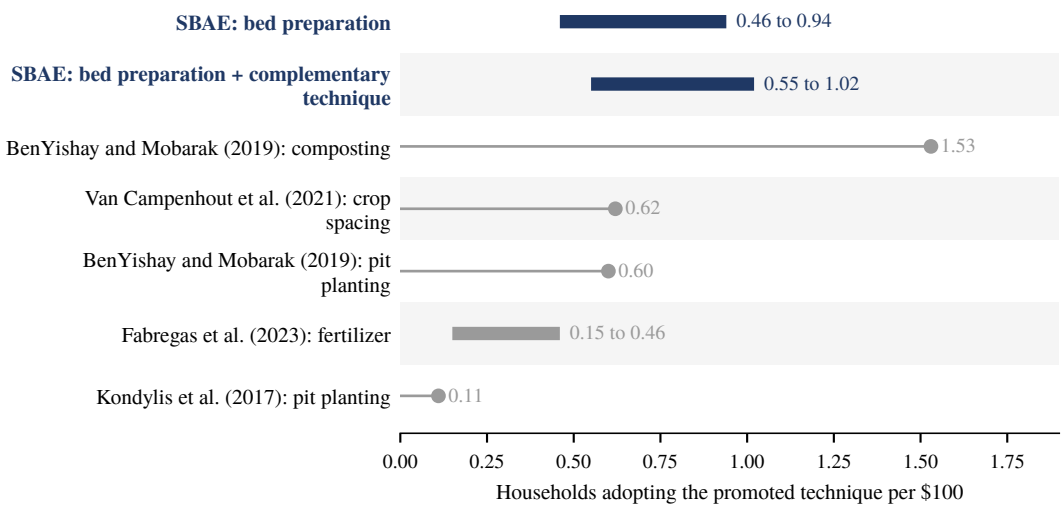
the most popular approaches to boosting school attendance in sub-Saharan Africa and among the most rigorously evaluated. Drawing on Baird et al. (2011)'s RCT in Malawi, Appendix Figure B3 shows that the augmented SBAE program (43.46 days per $100) is 1.7 to 2.5 times as cost-effective as CCTs (17.06–24.98 days per $100). My companion paper (Lee, 2026a) shows that this advantage widens further when SBAE is augmented with both parental engagement and information nudges signaling parents' openness to delegate farms to students: as students shift toward sales-oriented crops to finance school fees, cost-effectiveness rises to 59.51 days per $100—2.4 to 3.5 times that of CCTs.

Generalizability.

How generalizable are these results? I speculate that there would be a shift of balance between short-term and long-term benefits as SBAE is extended to countries that are higher up the ladder of economic development. The short-term benefits might become smaller for three reasons. First, there is less room to promote agricultural technologies that involve low monetary costs, can easily be used by students, and yet improve yields by a large extent. This would result in less dramatic increases in students' savings. Second, there is less room to improve school attendance as the dropout rates are much lower. Third, informational barriers are less likely to be the main constraints for parents' adoption of off-the-shelf agricultural technologies.

In the long term, however, SBAE's framework could generate more benefits for countries higher up the economic ladder, especially if SBAE could partner or integrate with complementary programs. First, the returns from promoting more advanced techniques, such as improved crop varieties and proper use of chemical fertilizers, would far exceed the returns from the promoted techniques in Liberia. While factors such as credit constraints would limit the use of these techniques, the SBAE framework remains powerful in alleviating information barriers about the extent of yield gains. Second, rather than encouraging school attendance per

Panel A. Technology adoption



Panel B. School attendance

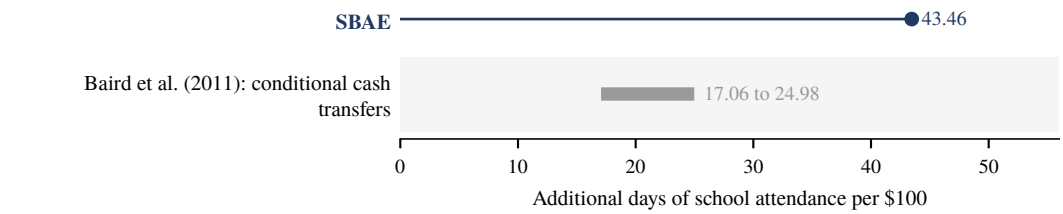


FIGURE B3. COMPARING THE AUGMENTED SBAE PROGRAM WITH ALTERNATIVES USING RANDOMIZED TRIAL EVIDENCE

Notes: This figure plots the cost-effectiveness of the augmented SBAE program (dark blue) and alternative programs evaluated in randomized trials (gray), in terms of impact per $100 invested. Panel A counts households adopting the main promoted technique; SBAE counts adoption of bed preparation on parents' parcels at endline (alone, or with a complementary soil management technique), and its range reflects assumed adoption of 0% to 5% among non-parent farmers within 2 kilometers of schools. The range for Fabregas et al. (2023) reflects 100 to 300 farmers reached per field day. Panel B counts additional days of school attendance; the range for conditional cash transfers is from Baird et al. (2011). Bars show ranges and dots single estimates. All monetary values are expressed in 2023 US dollars. Relevant calculations can be found in the Online Appendix.

se, education systems in these countries are more well-equipped to deliver the potential of student-centered learning under SBAE. In the very first step, SBAE could provide an entry point to train and motivate teachers to use more effective pedagogies in teaching science outside the few structured lessons related to agriculture, thereby improving students' understanding of and performance in science and related subjects. More importantly, the development of an educational culture that is centered on scientific understanding and open inquiries would facilitate bottom-up experimentation of farming techniques by students and their households, thereby sustaining the SBAE program without external extension support.

C Contrasting the marginal effects of the video and the farmer field day

Contrasting the marginal effects of the farmer field day and the promotional video sheds light on what drives households' technology adoption and the reversal of SBAE effects on students' school attendance. Both interventions provide information to parents, but of different types. The farmer field day offers hands-on technical training on promoted soil management techniques, which parents can employ while retaining students as assistants on family farms. The promotional video, by contrast, highlights how SBAE creates complementarities between students' agricultural work and education—emphasizing that students can manage farms independently and pursue further education to strengthen their skills as farmers. If the key constraint to technology adoption is parents' technical knowledge or program awareness, the farmer field day should have qualitatively similar effects as the video. If instead the constraint is parents' beliefs about the value of delegating farms to students and, more broadly, the returns to supporting students' education, the video should prove more effective—particularly for activating intra-household technology transfer—the second diffusion mechanism of SBAE.

Appendix Figure C1 presents the marginal effects on SBAE's first diffusion mechanism: parents' visits to school farms. Both the farmer field day and the promotional video play important roles in activating this channel. The farmer field day increases the fraction of parents who visit school farms by 7.3 percentage points and the number of visits in the second season by 0.47 (59% from the SBAE mean of 0.8); the video produces stronger, but qualitatively similar effects of 14.1 percentage points and 0.57, respectively. Similarly, both treatments increase the fraction of parents who observe school farm harvests (by 15 and 8.3 percentage points, respectively), the number of techniques parents learn from school (by 0.26 and 0.28, 150% and 160% from the SBAE mean of 0.17), and attendance at parent-teacher meetings (by 0.27 and 0.42, 48% and 75% from the SBAE mean of 0.56) in the third school year. Overall, therefore, the evidence suggests that both treatments are effective in encouraging parents to visit schools, learn promoted techniques, and monitor students' academic progress.

Appendix Figure C2 presents evidence on the second diffusion mechanism—intra-household technology diffusion from students to parents. Here, the video's dominance is stark. Only the video, not the farmer field day, increases the fraction of students who look after household farms. The video increases the fraction of students who look after farms by 7.3 percentage points at midline (significant at the 10% level) and 4.3 percentage points at endline (statistically insignificant), while the corresponding farmer field day effects are negligible (3 percentage points and -0.2 percentage points, respectively). More strikingly, the video's effect on the number of promoted techniques students demonstrate to their parents is approximately three times that of the farmer field day, and its effect on the number of techniques students advise parents to adopt on their own parcels is over ten times as large. In turn, the increase in the fraction of parents who report observing improved cassava yields on students' parcels is substantially higher with the video (13.7 percentage points) than with the farmer field day (4.3 percentage points)—a ratio of more than three to one. Overall, therefore, the evidence suggests that the video, not the farmer field day, plays a dominant role in activating the second diffusion mechanism of SBAE.

As highlighted in the introduction, since farmers prefer learning from socioeconomic peers (BenYishay and Mobarak, 2019), observing technologies under familiar conditions (Munshi, 2004), and gathering multiple observations before adopting (Beaman et al., 2021), students' home projects—SBAE's second diffusion mechanism—could prove pivotal in overcoming barriers for technology adoption. Consistent with this, Figure 9 shows that while both treatments contribute to technology adoption on students' parcels, only the video produces effects strong enough to increase adoption on parents' parcels. This has significant implications for households' production, as parents' production tends to be bigger in scale and generate far greater farm sales than students' parcels. Similarly, consistent with the video reshaping parents' aspirations for their children's education, the video accounts for the entire reduction in student dropouts, and, correspondingly, the entire increase in the total number of days students attend school.

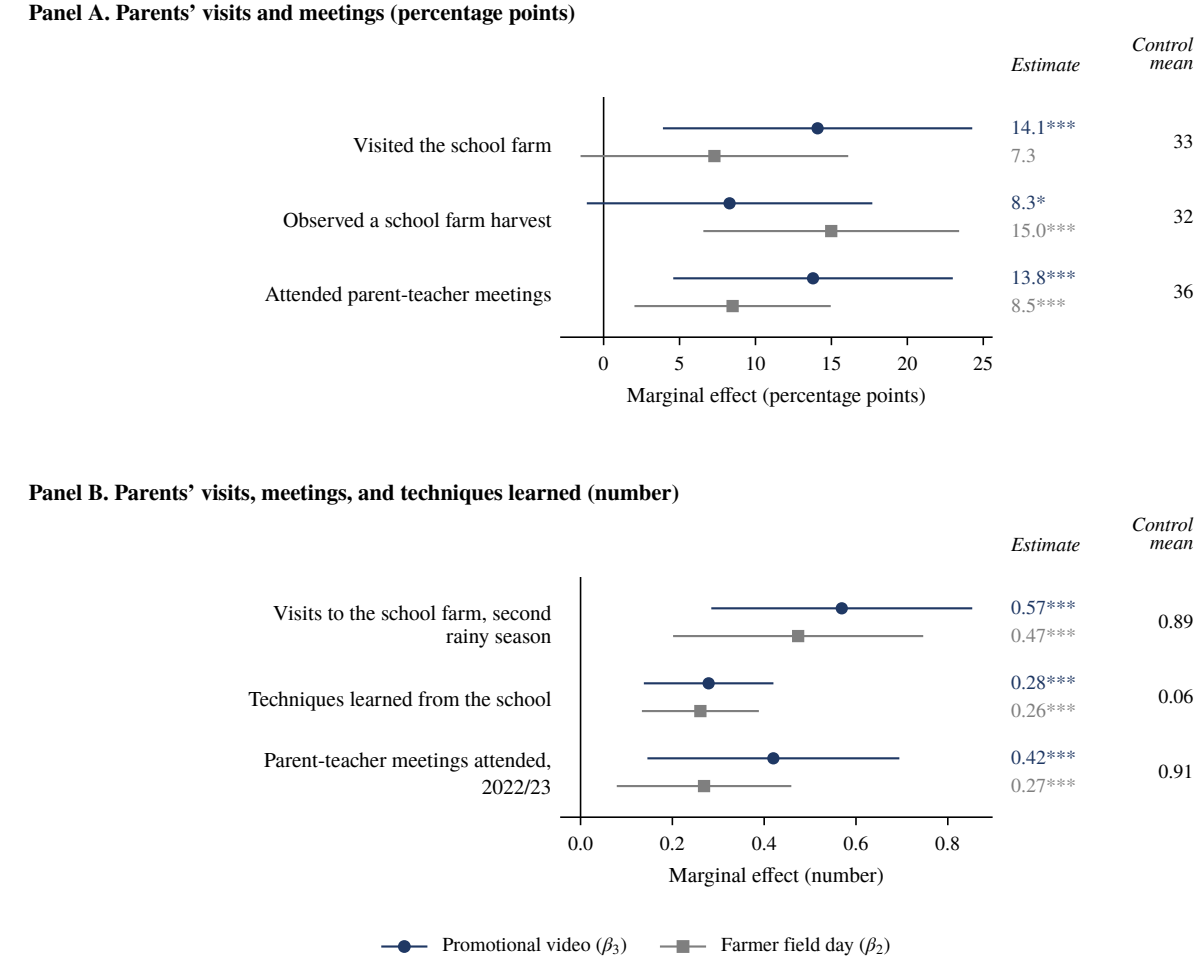


FIGURE C1. CONTRASTING MARGINAL TREATMENT EFFECTS ON PARENTS' VISITS TO SCHOOLS

Notes: This figure plots the marginal effects of the promotional video (β_3 in (1); dark blue circles) and the annual farmer field day (β_2; gray squares). Panel A reports indicator outcomes in percentage points; Panel B reports counts. Horizontal bars are 95% confidence intervals based on standard errors clustered at the geographical-cluster level. All outcomes are from the endline parent survey. Visits are counted for the second rainy season (2022) and parent-teacher meetings for the 2022/23 school year. Full estimates, including β_1 and $\beta_1 + \beta_2 + \beta_3$, are in the even-numbered columns of Online Appendix Table OA14. Significance: *** p<0.01, ** p<0.05, * p<0.10.

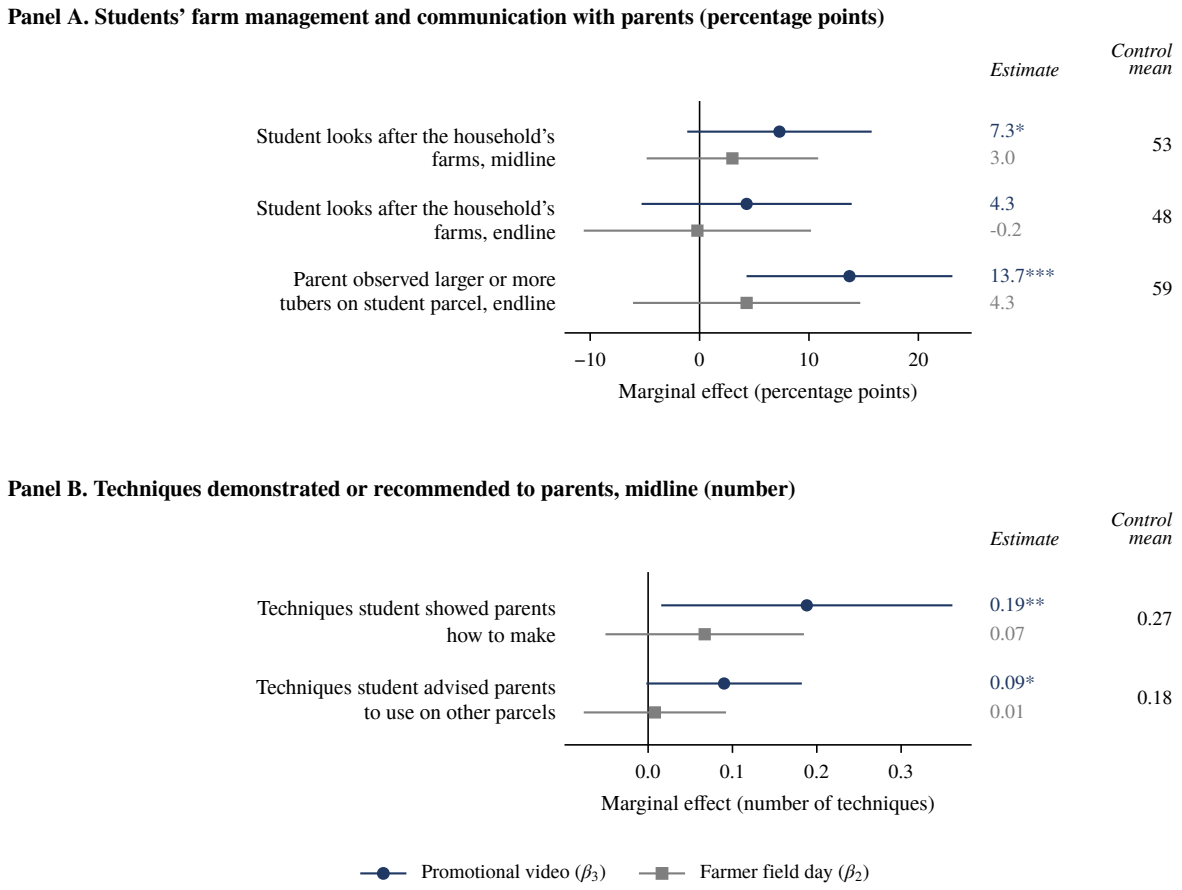


FIGURE C2. CONTRASTING MARGINAL TREATMENT EFFECTS ON INTRA-HOUSEHOLD TECHNOLOGY DIFFUSION

Notes: This figure plots the marginal effects of the promotional video (β_3 in (1); dark blue circles) and the annual farmer field day (β_2; gray squares). Panel A reports indicator outcomes in percentage points; Panel B reports counts. Horizontal bars are 95% confidence intervals based on standard errors clustered at the geographical-cluster level. Looking after the household's farms and the numbers of techniques shown and advised are student reports; the observation of larger or more tubers on the student's parcel is a parent report from the endline. "Other parcels" are parcels other than the student's own. Full estimates, including β_1 and $\beta_1 + \beta_2 + \beta_3$, are in the even-numbered columns of Online Appendix Table OA15. Significance: *** p<0.01, ** p<0.05, * p<0.10.