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Adoption of High-Yielding Groundnut Varieties: The Sustainability of a Farmer-Led Multiplication-Dissemination Program in Eastern Uganda

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Abstract: This study examines the adoption of high-yielding varieties (HYVs) of groundnut by smallholders in eastern Uganda. The primary focus of this work is the analysis of the sustainability of impacts from a regional farmer-led HYV dissemination and multiplication program. Data collected in 2014 is used to determine the lasting impact of the program conducted a decade prior, from 2001 to 2004. The structure of the data, which includes a treatment and 2-part control group, is critical to the identification of project impacts, measured as groundnut land allocation to groundnut HYVs (%). Fractional regression, propensity score matching and instrumental variable techniques are utilized to address potential bias from model specification, selection, and endogeneity. We find that, on average, participating households allocated 21% more of their land in groundnuts to HYVs relative to controls. Diffusion of program benefits through spillover is revealed by statistically significant differences in mean adoption between neighbor and non-neighbor controls, such that benefits are transferred from participants to their neighbors but not to the non-neighbor control group. We also find that, because of seed saving practices, the average yield for HYVs decreased over time to levels below those obtained from landrace varieties. Thus, the program effectively aided in information dissemination and technology transfer within rural communities. However, additional knowledge transfer is critical to the sustainability of food security outcomes among participant farmers.

Keywords: technology adoption; high-yielding seeds; groundnuts; impact evaluation; fractional regression; instrumental variables; propensity score matching; Uganda; Sub-Saharan Africa

1. Introduction

Groundnuts are a major crop in Uganda, ranking 11th in production and 6th for area harvested in 2013 and 2014 [1]. Comparison across African countries over the same time period places Uganda in the top third for total harvest and proportion of farmland allocated to groundnuts. However, pressure from disease and drought has resulted in low groundnut yields, and, under the yield category, Uganda is among the bottom third of African countries. To address this low productivity, Ugandan plant breeders have become well-known for the development of high-yielding varieties (HYVs) of groundnut that exhibit disease and drought resistance [2]. Furthermore, recent studies of smallholders in Uganda have demonstrated the benefits of adopting groundnut HYVs [3–6], and how farmer networks can help to facilitate adoption [7,8]. This pattern of results begs the question: have efforts to promote HYVs led to increased adoption?

To address this matter, the literature on seed adoption generally relies on two sources of data. The first consists of large representative surveys, e.g., the World Bank's Living Standards Measurement Study—Integrated Surveys on Agriculture, that are used to evaluate trends in country-wide adoption [9–11]. The second type of data is collected to analyze outcomes from microstudies, which is the case in this article. These datasets are made up of one or more surveys to examine impacts from specific programs or policies that promote adoption, and data is collected during or very close to implementation, either immediately before and/or after the program or policy is enacted [12]. Due to concerns with attrition and contamination, data is often not collected over long periods of time. However, having a well-designed sample makes it possible to examine the longer-term impact of projects, which is important but rarely found in the literature. In this study, therefore, we address this gap in the literature and offer a contribution by examining the sustainability of project impacts on adoption of HYVs. As a case study, our research focuses on a groundnut HYV multiplication and dissemination program conducted in eastern Uganda during the early 2000s [13].

In the broader context, our work is motivated by the critical task of bringing about a smallholder productivity revolution in response to the impending challenges to global food security [14]. Rural communities throughout the world rely on smallholder farming as a primary source of food and fiber [15]. The task of meeting the nutritional and financial needs of the household (HH) must be hard-won given the inherent risk associated with agricultural production. Within Sub-Saharan Africa (SSA), agricultural production is dominated by smallholder HHs that make up around 80% of farms [16]. Furthermore, this region faces significant persistent challenges from global climate change, e.g., drought and plant diseases [17,18]. As a recent contribution to the analysis of food insecurity, the development resilience framework encompasses mitigation strategies and supports the general conclusion from earlier studies that greater food security must be achieved through increased returns to farmers' resources [19–21]. The framework states that an individual or HH is resilient if they are able to withstand shocks and stressors without falling into poverty [22]. Correspondingly, agricultural productivity growth and off-farm employment are essential to reducing food insecurity in SSA via increased HH income and poverty reduction [23–25]. At the same time, pressures placed on urban food systems remain due to increases in off-farm employment and related urbanization [26]. Ultimately, a balanced path forward is needed as smallholders face a burden of uncertainty under mounting pressures [23].

Experts have found that productivity per agricultural worker in SSA has increased by a factor of 1.6 over the last 30 years compared to 2.5 in Asia over the same period [16]. This difference is attributed to greater reliance on area expansion and lagged development of region-specific HYVs in SSA relative to Asia, where intensification has dominated [27]. In lieu of global climate change concerns, sustainable intensification (SI) has become an increasingly important policy goal [28,29]. Thus, our study is motivated by the premise that projects to promote technology adoption and mitigation of risks associated with crop production are an effective means of support to smallholders and increase sustainability of local food systems. In SSA, these projects foster SI, moving away from historical reliance on area expansion. Moreover, there is evidence of an inverse relationship between farm or plot size and input use intensity associated with the adoption of modern inputs such as, machinery, chemicals, irrigation, and HYVs [10]. However, other evidence suggests that intensification across SSA countries has been weak compared to predictions from the literature [30].

Often, development projects are designed to mitigate the primary constraints to technology adoption by increasing availability and reducing the cost of traditional and modern inputs, such as fertilizer and HYVs [31]. Furthermore, HYVs have been targeted in many cases and empirical evidence reveals that the dissemination and adoption of HYVs increases productivity growth for staple crops among smallholders. It is also observed that these trends vary by region and crop [10,32,33]. Thus, we explore the sustainability of adoption outcomes for a particular project that attempted to promote HYVs to small-scale groundnut producers in eastern Uganda.

The remainder of the paper is structured as follows: Section 2 provides a brief review of the literature on HYV adoption and groundnut production in Uganda, as well as a description of the project; next, Section 3 introduces the data, along with the methodological framework that is applied to examine program impact; Section 4 presents our findings; and the Section 5 offers final insights based on our findings.

2. Background

2.1. Seed Adoption Literature

Stemming from breakthroughs in hybrid seed development by plant breeders and geneticists, early work on seed adoption focused on agro-ecological suitability, which followed from the epidemiological literature, where, given appropriate conditions, diffusion occurs naturally [34]. However, follow-up studies suggest that even if agro-ecological conditions are suitable, the natural diffusion process is fraught by barriers that deter adoption [35]. More generally, the literature has demonstrated consistently that availability of new technologies must be complemented by sufficient outreach and education for adoption to occur, which often relies on pre-existing social networks [36–41]. Economic feasibility is also critical to adoption, and the theoretical underpinning is framed as a utility maximization problem where HH i adopts if the expected utility from adoption (U_{iA}) is greater than non-adoption (U_{i0}), i.e., $U_{iA} - U_{i0} > 0$ [3]. This seemingly straightforward condition becomes nuanced for smallholders given the various factors they face including: (1) input fixity; (2) portfolio selection; (3) safety first behavior; (4) liquidity constrains; and (5) farmer experimentation and learning [42]. As a result, land allocation to HYVs is rarely 100% among smallholders [43]. To promote adoption, governmental and non-governmental organizations work to make new technologies readily available, lowering the overall cost to poor HHs and eliminating bottlenecks, thereby easing key constraints to adoption [44]. This work often comes in the form of targeted development programs coupled with impact assessments to evaluate outcomes.

Impact assessment of agricultural innovation is a growing body of research driven by significant public investment in the field [45]. The literature on HYV adoption, which has relied largely on micro-studies of programs, has several limitations that require further research [12]. One such limitation is the scant attention given to the sustainability and spillover effects of project outcomes, whereby project benefits are transferred from participants to non-participants as a function of physical proximity (neighbors) and social networks [31]. Thus, more work is needed to examine the premise that short-term responses to treatment may differ from longer-term outcomes and that spillover effects may be significant. A well-known example from the development literature is the 2004 *worms* study in Kenya by Miguel and Kremer who found that the effectiveness of treatment diminished rapidly over time, while the effective spillover benefits to the untreated were also short-lived [46]. In their 2007 follow-up article, Miguel and Kremer consider the sustainability of development program outcomes and suggest that continual or recurring treatments are more cost-effective compared to one-time projects that assume sustained impact through diffusion of program benefits [47].

A 2014 paper by Carter et al. presents a theoretical model of sustainable adoption and examines whether one-time input subsidies result in an ongoing pattern of adoption for underutilized inputs (e.g., fertilizer and seeds) [31]. Using adoption data for the two years following a one-time subsidy program for agricultural inputs in Mozambique, they find increased HH adoption rates for fertilizer that are sustained over the subsequent seasons, whereas HH adoption of HYVs did not change. To explain their finding for HYVs, the authors infer that adoption by the target population prior to the program was already at near optimal levels. An alternative interpretation of this finding, following Miguel and Kremer (2007), is that one-time interventions may be ineffective compared to programs with recurring benefits [47]. In particular, HYVs require updating with the release of new varieties better suited to the changing climate and adapted to emerging environmental and biological threats. The effectiveness of continuous treatment is exemplified through the extension approach that relies on the feedback loop between growers, researchers, and educators, which has been well documented [48].

It is important to highlight that certain crops, such as groundnuts, are open pollinated (about 99%) and seed saving is effective for up to 10 production cycles (i.e., 5 years assuming 2 cropping seasons per year). Thus, after a few years we expect the vigor of the initial seeds to decline (due to inbreeding) necessitating replenishment of the genetically pure seed stock. These recommendations are often ignored and farmers save their seeds longer than recommended, thereby incurring yield losses due to inferior performance. For groundnuts, there is a recommended variety replacement period of 6–8 years post release. Therefore, it is common that new varieties are released with similar profiles but superior characteristics to the older variety being replaced, e.g., higher yields, more disease tolerance, and other desired attributes [49]. Yet, new variety adoption is subject to market availability and HH access to capital for seed purchases. Smallholder access to capital has received attention over recent years with several studies that examine the role of microcredit in agricultural development [50].

The segment of the adoption literature that considers markets, farmer networks, and policy in relation to smallholder access to HYVs has also received significant attention. Generally, researchers examine formal and informal channels that determine whether or not seed reaches HHs [51]. Commercial seed companies, operating through formal market channels, increase access where demand is sufficient to generate profits [52]. In addition, scaling up production through regional harmonization of seed systems can boost the profitability of commercial seed companies [53]. Informal farmer seed networks provide a variety of benefits to smallholders and can also benefit from regionalization [54]. These informal channels offer a means of information sharing and provide a check against formal ones. An example is awareness of counterfeit seeds and other adulterated agricultural inputs, the presence of which is both exploitive and a disincentive to adoption, and has been identified as a growing problem [55]. In Uganda, concerns over counterfeit seed have led to quality assurances, e.g., Certified seed from commercial seed companies and Quality Declared Seed produced by famer groups, and to the development of a robust early generation seed system [56]. Ultimately, broad-based engagement through formal and informal channels to promote access, availability, affordability, and adoption of high-quality HYVs among smallholders is essential given the clear benefits to food insecure HHs. HYVs can also counteract the adverse effects of increased environmental pressures from global climate change [3,57,58].

2.2. Groundnut in Uganda

Crops expected to have a significant regional impact on increasing food security among the rural poor are often the target of development programs [14]. Groundnut is a staple throughout SSA and has received attention because it provides a variety of nutritional benefits, and is a nitrogen fixing legume that can be used in crop rotations to improve soil quality. In Uganda, groundnut is a valuable crop that is primarily sold domestically in local markets and given a moderate yield it is highly profitable compared to other staple crops [2]. Groundnuts are sorted and graded by quality and are valued according to attributes (e.g., color and size) to ensure faster sale in the market. In urban markets, the lowest quality groundnuts, including shriveled, cracked, and moldy ones, are usually crushed into products like flour and sauces, whereas in rural areas, this low-grade product is used for home consumption, animal feed, or is discarded.

Following a peak in production during the early 1970s (251,000 tons on 291,800 hectares (ha)), Uganda experienced major declines in domestic groundnut output but has seen steady growth in more recent years, surpassing the 1970s highs for the first time in 2009 and peak domestic production in 2011 (357,000 tons on 409,000 ha) [2,6]. These increases are largely attributed to the uptake of alternative farming practices and HYVs [5,59]. It is estimated that groundnut producers in Uganda benefit significantly from HYVs, exhibiting average yield gains of 35% and average per unit cost reductions of around 40% [3]. Given research indicating yield losses from pests and disease, particularly the rosette virus, have exceeded losses from poor soil, drought, and inferior planting material, plant breeders have identified promising groundnut varieties that are high-yielding as well as disease and drought resistant [60–62].

The National Semi Arid Resources Research Institute (NaSARRI) in Soroti, which is part of Uganda's National Agricultural Research Organization (NARO), has released a number of HYVs over recent years through collaborative efforts between domestic and international geneticists and plant breeders [63–65]. Yet, in 2002, 90% of all crops in Uganda, including groundnuts, consisted of landrace varieties (LRVs) from home-saved seed, and by 2014, this share remained between 85% and 90% [66,67]. These findings are not surprising given limited access, liquidity constraints, and the relatively high cost of purchased seeds, as well as concerns over the prevalence of counterfeit seeds [68].

Valuable support from extension services to smallholders provided by the Uganda National Agricultural Advisory Services (NAADS), which lists groundnut as a major crop, helps to promote on-farm practices to enhance smallholder welfare, resulting in estimated gross agricultural revenue increases between 37% and 95% to participating HHs, and an internal rate of return on program investments ranging from 8% to 49% [69,70]. On the other hand, the availability of these services is limited and attention is given to priority areas that are set based on need and expected impact on a regional basis. With significant gains to be made, NGOs frequently supplement state extension services, receiving public and private funds through grants to engage with smallholders [45,71]. One such organization is Appropriate Technology Uganda (ATU), which was established to enhance linkages between HHs in eastern Uganda and NaSARRI (http://www.nasarri.go.ug).

2.3. The ATU Farmer-Led Multiplication and Dissemination Program

The diagnostic results from a 1999 survey of farmers in eastern Uganda provided the basis and justification for the farmer-led Groundnut Seed multiplication and dissemination Program (GSP). The survey conducted by ATU revealed that groundnuts, despite their high profitability compared to other crops, were not being grown by poor farmers because of the risk associated with production [13]. The use of HYV seeds can be a cost-effective and sustainable means to mitigate this risk, but a major hurdle to adoption is the relatively high cost of purchased seed [4,67]. Lessons from previous ATU projects indicated that farmer-led seed multiplication is an effective means of promoting access to and utilization of HYVs and alternative farming practices. In addition, recent studies in Uganda have demonstrated the effectiveness of farmer networks in fostering technology innovation and the adoption of HYVs [7,8,72].

GSP was carried out from 2001 to 2004 with funding from the United Kingdom Department for International Development [13]. The ATU organization provided access to HYVs and placed the process of collection, redistribution, and monitoring of multiplied seed in the hands of local leaders from participating farmer groups. These groups received seed stock for multiplication and distributed the materials to members (participants) as a seed loan. Repayment of the loan was due upon harvest in the form of returned groundnut seed in the amount provided at the beginning of the growing season. Figure 1 illustrates the various linkages between NaSARRI, ATU, and participating HHs during GSP. Outcomes were evaluated at the end of the project in 2004 via a HH survey, which are assessed and documented in the 2004 ATU Final Technical Report [13]. After 2004, any remaining HYV multiplication and dissemination efforts were effectively turned over to independent farmer groups.

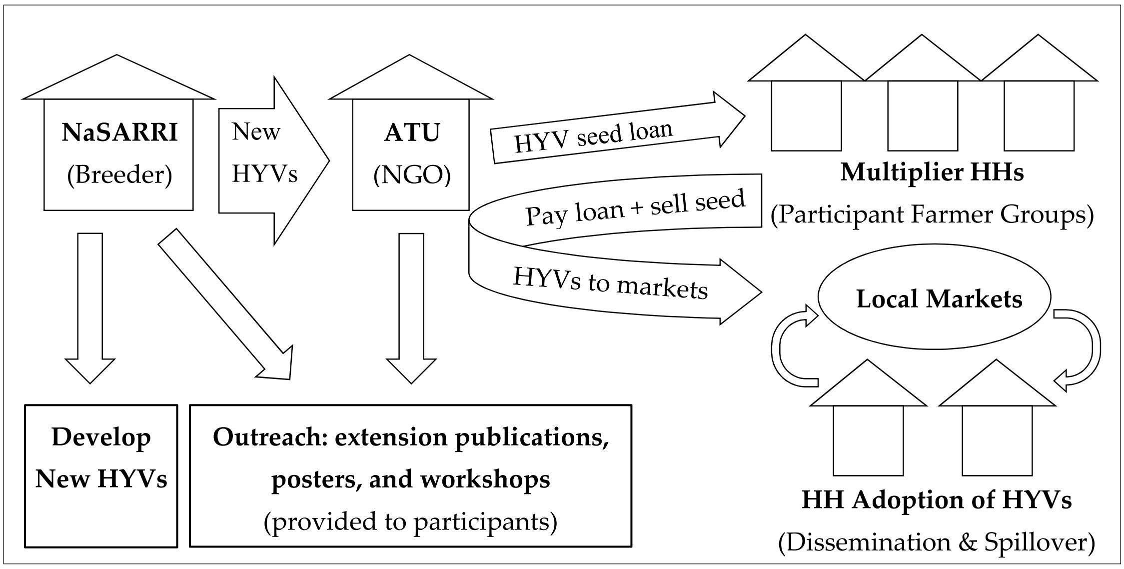

Figure 1. Schematic of farmer-led multiplication and dissemination program.

3. Materials and Methods

3.1. Data

The data used in this study comes from the 2004 survey mentioned above and a follow-up survey of the same HHs done in 2014. Both surveys include the same general questions with added questions in the 2014 survey on groundnut seed varieties and land allocation to assess the nature of HYV adoption in greater detail. HHs included in the surveys produced groundnuts during the 2004 growing season and were located in eastern Uganda. At the outset of the GSP, project locations in eastern Uganda were selected randomly to avoid placement bias.

Uganda is divided into 112 districts and each district is subdivided into 1 to 5 counties for a total of 181 counties, which are then split into 1382 sub-counties. Sub-counties are divided into parishes that are made up of a group of villages with many HHs [73]. The project was located (*LOC*) in 8 districts in eastern Uganda, within a randomly selected sub-county in each of the districts (Table 1). A participating and a non-participating parish were randomly chosen within each of the 8 sub-counties. In each parish, groundnut producing HHs were identified. In participating parishes, HHs were separated by category into either participants (farmer group members) or non-participant neighbors. The GSP participant group (*BEN*) consists of 30 HHs per participating parish, with 10 HHs randomly selected from 3 farmer groups, for a total of 240 *BEN* HHs. The GSP control group (*C_ALL*) is composed of two sub-groups: (1) Neighbors (*C_IN*), consisting of 15 HHs per participating parish, with 5 HHs randomly selected for each of the 3 farmer groups from the list of eligible groundnut producing neighbors, for a total of 120 *C_IN* HHs; and (2) Non-neighbors (*C_OUT*), consisting of 15 HHs randomly selected from each non-participating parish, for a total of 120 *C_OUT* HHs. The full sample includes 480 HHs; 240 *BEN* and 240 *C_ALL* divided into 120 *C_IN* and 120 *C_OUT*.

The 2014 survey report from the ATU organization describes attrition in the sample between the 2004 and 2014 surveys. It shows that 87% of respondents participated in both rounds of the survey, members of the same HHs were surveyed in 96% of cases, with only 4.2% of the 2014 sample consisting of randomly selected replacement HHs. We also consider another form of attrition related to groundnut production keeping in mind that for HHs to be eligible for the 2004 survey they had to grow groundnuts. In 2014, 78% of HHs in the sample still grew groundnuts, which ranged from 71% for *C_IN* to 82% for *C_OUT* (Table 2). These rates vary significantly by HH location with *LOC_6*, *LOC_8*, and *LOC_4*, experiencing the greatest declines in groundnut producing HHs respectively, and this attrition is consistent across beneficiary and control groups. Based on information from local experts, these patterns reflect shifts in specialization over time towards other crops particularly maize.

Table 1. List of Variables and Definitions by Category.

Variable	**Definition**
	Outcome Indicator
ADOPT	Groundnut land allocation to HYVs (%)
	Participation
BEN	Participant (1 = yes, 0 = no)
C_IN	Control neighbor (1 = yes, 0 = no)
C_OUT	Control non-neighbor (1 = yes, 0 = no)
PV	Project village (1 = yes, 0 = no)
	Demographic Characteristics
GRESP	Gender of respondent (1 = male, 0 = female)
HH_SIZE	Total HH members (#)
LOC	Location: Sub-county, District (1 = Nyero, Kumi; 2 = Kidongole, Bukedea; 3 = Kasodo, Pallisa; 4 = Lyama, Budaka; 5 = Kachonga, Butaleja; 6 = Nagongera, Tororo; 7 = Butiru, Manafwa; and 8 = Bukhalu, Sironko)
AGE	Age household head (HHH) (years)
GHHH	Gender HHH (1 = male, 0 = female)
EDU	Schooling HHH (1 = none, 2 = primary, 3 = secondary, 4 = tertiary)
M_STAT	Married HHH (1 = yes, 0 = no)
	Agricultural Production
AREA	Total area cultivated (ha)
MEM	Member of a farm group (1 = yes, 0 = no)
GROW	Grew groundnuts 2013 Season A (1 = yes, 0 = no)
SAVE	Groundnuts grown from home saved seed (1 = yes, 0 = no)
G_CASH	Groundnuts grown as cash crop (1 = yes, 0 = no)
G_AREA	Area allocated to groundnuts (ha)
G_PROP	Proportion farmland in groundnut production (%)
COST	Cost of groundnut seed (per kg) 2013 season A (*USD* *)
SEED	Quantity of groundnut seed planted 2013 season A (kg)
HARV	Quantity groundnut (unshelled) harvested 2013 season A (kg)
YIELD	Yield groundnuts (unshelled) 2013 season A (kg/ha)
	Groundnut Varieties
LRV	Land race varieties (1 = Red Beauty ^; 2 = Igola 1 ^; 3 = Erudurudu Red; 4 = Etesot; 5 = Magwere; 6 = Kitambi)
HYV	High yielding varieties (1 = Serenut1; 2 = Serenut2; 3 = Serenut3; 4 = Serenut4; 5 = Serenut5; 6 = Serenut6)

Note: * Ugandan Shillings (USh) converted to USD using 12/31/2013 exchange rate of 2525 USh/USD. ^ Varieties reclassified as LRVs, originally released as HYVs.

Table 2. HH Demographics for Different Farmer Groups in Eastern Uganda.

	Pooled	***BEN***	***C_ALL***	***C_IN***	***C_OUT***
GRESP	0.48 (0.501)	0.39 (0.488)	0.57 (0.495)	0.50 (0.501)	0.62 (0.486)
HH_SIZE	8.47 (3.99)	8.24 (3.98)	8.70 (4.00)	8.35 (4.18)	9.05 (3.79)
AGE	51.4 (12.9)	53.2 (12.9)	49.6 (12.7)	49.9 (14.0)	49.3 (11.3)
GHHH	0.79 (0.407)	0.79 (0.407)	0.79 (0.407)	0.81 (0.395)	0.78 (0.419)
EDU_1	0.14 (0.343)	0.15 (0.358)	0.12 (0.327)	0.12 (0.332)	0.12 (0.322)
EDU_2	0.56 (0.497)	0.53 (0.500)	0.59 (0.493)	0.64 (0.481)	0.54 (0.500)
EDU_3	0.21 (0.410)	0.20 (0.404)	0.22 (0.416)	0.17 (0.382)	0.27 (0.444)
EDU_4	0.09 (0.286)	0.11 (0.317)	0.07 (0.250)	0.06 (0.235)	0.07 (0.264)

Table 2. *Cont.*

	Pooled	***BEN***	***C_ALL***	***C_IN***	***C_OUT***
M_STAT	0.82 (0.382)	0.80 (0.404)	0.85 (0.358)	0.83 (0.374)	0.87 (0.341)
AREA	1.64 (1.05)	1.60 (1.01)	1.68 (1.09)	1.48 (0.88)	1.89 (1.24)
MEM	0.61 (0.489)	0.97 (0.180)	0.25 (0.431)	0.19 (0.395)	0.30 (0.460)
GROW	0.78 (0.415)	0.80 (0.404)	0.76 (0.426)	0.71 (0.456)	0.82 (0.389)
n	480	240	240	120	120

Note: mean coefficients; standard deviation (sd) in parentheses.

Variables are defined in Table 1. Table 2 contains summary statistics for HH demographic variables for the full sample (*N* = 480) and these are consistent with the statistics for the sub-sample of groundnut producers (*N* = 374). Table 3 summarizes groundnut production. Demographic characteristics between participant and control groups are not found to be statistically significant, with few exceptions, e.g., *AREA* and *AGE* for *BEN* versus *C_IN* (Table 2). Among groundnut producing HHs in 2013 season A, 63% grew HYVs, with 70% *BEN*, 64% *C_IN*, and 50% *C_OUT* (Table 3). On average, 21% of the land cultivated (0.32 ha) is allocated to groundnuts (*G_AREA*), and 52% of this area to HYVs (Table 3). Different rates (%) across farmer groups are attributed to project participation with the highest rate for *BEN* (97%) and lowest for *C_IN* (22%) followed by *C_OUT* (34%) (Table 3). With respect to production, 91% of producers grew groundnut as a cash crop and 49% utilized home saved seed. In 2013 season A, the average HH planted a total of 24.8 kg, harvested a total 166 kg, and achieved a yield of 97.3 kg/ha (Table 3).

Table 3. Production for Groundnut Growers in 2013 Season A.

	Pooled	***BEN***	***C_ALL***	***C_IN***	***C_OUT***
ADOPT	0.52 (0.452)	0.56 (0.439)	0.48 (0.463)	0.56 (0.463)	0.40 (0.452)
AREA	1.77 (1.07)	1.71 (1.04)	1.84 (1.11)	1.62 (0.85)	2.02 (1.27)
MEM	0.64 (0.482)	0.97 (0.160)	0.28 (0.452)	0.22 (0.419)	0.34 (0.475)
GROW_HYV	0.63 (0.483)	0.70 (0.461)	0.57 (0.497)	0.64 (0.482)	0.50 (0.503)
SAVE	0.49 (0.501)	0.55 (0.498)	0.42 (0.495)	0.40 (0.493)	0.44 (0.499)
G_CASH	0.91 (0.284)	0.91 (0.293)	0.92 (0.275)	0.95 (0.213)	0.89 (0.317)
G_AREA	0.32 (0.378)	0.34 (0.457)	0.30 (0.271)	0.28 (0.242)	0.32 (0.294)
G_PROP	0.21 (0.304)	0.24 (0.405)	0.18 (0.128)	0.17 (0.123)	0.18 (0.132)
COST	1.002 (1.060)	1.001 (1.081)	1.003 (1.041)	0.946 (1.023)	1.052 (1.060)
SEED	24.8 (35.0)	26.0 (44.4)	23.5 (21.3)	22.0 (19.3)	24.7 (22.8)

Table 3. *Cont.*

	Pooled	*BEN*	*C_ALL*	*C_IN*	*C_OUT*
HARV	166 (226)	170 (240)	162 (210)	166 (238)	160 (183)
YIELD	97.3 (90.3)	102.4 (97.7)	92.0 (82.0)	92.6 (78.9)	91.4 (85.0)
n	*374*	*191*	*183*	*85*	*98*
YIELD_LRV	114.0 (94.2)	116.2 (98.2)	111.9 (90.5)	119.2 (87.5)	107.0 (92.7)
n	*218*	*108*	*108*	*44*	*110*
YIELD_LRV_1	133.7 (100.7)	135.5 (98.9)	131.9 (103.2)	139.9 (95.4)	124.1 (111.3)
n	*125*	*62*	*62*	*31*	*63*
YIELD_HYV	86.2 (87.9)	95.4 (97.6)	74.5 (72.4)	77.6 (77.7)	71.1 (66.7)
n	*236*	*133*	*133*	*54*	*103*
YIELD_HYV_2	77.8 (75.9)	84.5 (85.3)	69.5 (61.6)	66.5 (56.1)	72.6 (67.4)
n	*219*	*121*	*98*	*51*	*47*

Note: mean coefficients; sd in parentheses.

The *Pooled* average yield for LRVs and HYVs are 114.0 kg/ha and 86.2 kg/ha, respectively (Table 3). The *BEN* and *C_IN* groups achieve similar yields for LRVs, while *BEN* produces significantly greater yields for HYVs (Table 3). Average yields for the two most commonly grown varieties, Red Beauty (*LRV_1*) and Serenut 2 (*HYV_2*), are 133.7 kg/ha and 77.8 kg/ha, respectively (Table 3). We find that yield for Serenut 2 is statistically higher for *BEN* compared to *C_IN* and *C_OUT*, at the 5% and 1% levels respectively (statistical differences are determined using 2-sided t-test for differences in means). Home saved seed is used as planting material by 41% and 53% of HHs for LRVs and HYVs, respectively (Table 3). According to the most common varieties, home saved seed is used by 34% for Red Beauty and 53% for Serenut 2 (Table 3). Furthermore, reliance on home saved seed can help to explain the relatively low yields reported for HYVs compared to LRVs [12].

3.2. Methodological Framework

The data from the 2014 survey is considerably richer than the data from 2004, so we use the former and a cross-sectional approach to estimate the models that follow. Controlling for various exogenous factors, we assume that the association between adoption and program participation provides a good estimate of the impact of GSP. First, the effect of the program is evaluated via the following model (i) estimated with ordinary least squares (OLS):

$$ADOPT = \alpha_i + \gamma BEN + \delta C\_IN + \beta_i x + \mu_i \qquad (i)$$

where *ADOPT*, measured as the share (%) of groundnut area allocated to HYVs, is regressed on *BEN* and *C_IN* (*C_OUT* is the excluded category) and a vector of covariates (x) of HH characteristics (*GRESP*, *HH_SIZE*, *LOC*, *AGE*, *GHHH*, *EDU*, *M_STAT*, and *AREA*). All of these variables are defined in Table 1.

Model (ii) is a variant of model (i), where *ADOPT* is regressed on HH location in a Project Village (PV):

$$ADOPT = \alpha_{ii} + \pi PV + \beta_{ii} x + \mu_{ii} \qquad (ii)$$

where *PV* = 1 for both *BEN* and *C_IN*, and *PV* = 0 for *C_OUT* (the excluded category).

The specifications of the models above (unrestricted) are re-estimated excluding the vector of covariates (restricted). These two specifications are contrasted and the preferred model is selected based on F-test results. The terms α, β and μ (error term), are parameters to be estimated. In model (i), γ measures the impact on participant HHs and δ on non-participant neighbors. In model (ii), π measures the impact of GSP on all HHs from project villages.

The dependent variable, percentage of groundnut area allocated to HYVs *(ADOPT)*, ranges from 0 to 1 in models (i) and (ii). Statistical models used historically to estimate this type of fractional outcome variable with boundary observations, typically the two-limit tobit, face conceptual challenges and have been shown to result in biased estimates [74]. In this context, fractional regression methods have been proposed and implemented, and have gained support as a means to handle bias from model misspecification [75]. Alternative fractional regression (FR) estimation methods include nonlinear least squares (NLS), quasi-maximum likelihood (QML), and beta-based maximum likelihood (ML). Alternative specifications of the functional form of the conditional mean, $\mathrm{E}(y|x)$, include the cauchit, logit, probit, loglog, and cloglog specifications [74]. Given these options it is important to select a model that is best suited for the data under analysis. One approach is to apply likelihood tests to determine the goodness of fit for the alternative models [74]. For our analysis, the QML estimation method is selected along with the probit specification because this configuration has some distinct advantages outlined by Papke and Wooldridge [76].

Another issue in impact evaluation work that we need to contend with when using cross sectional data concerns biases from observable and unobservable variables. To mitigate such biases, the ideal is to observe a group at a given point in time in both the treated and untreated states. Clearly this is not possible; thus, it is necessary to create a counterfactual in order to attribute any changes in the indicator of interest to the intervention [77]. The standard means to generate a robust counterfactual is for the researcher to randomly allocate a sample of individuals from the study population into treated and control groups. However, randomization is often difficult in the social sciences, and researchers must resort to quasi-experimental study design alternatives [78–80]. Propensity Score Matching (PSM) is widely-used to handle biases from observables, while Instrumental Variables regression (IV) can mitigate biases from both observables and unobservables [81].

PSM uses observable characteristics of individuals in the sample to generate a control group that is as similar to the treated group as possible except for intervention status [82]. Two conditions must be met for PSM estimation: (1) observable characteristics must be independent of project outcomes, i.e., conditional independence; and (2) there needs to be overlap in the distributions of observable characteristics between treated and untreated, i.e., common support [83]. PSM begins by regressing treatment status (1 for treated and 0 for controls) on a vector of observable characteristics to generate propensity scores [84]. This first step is usually done via probit or logit estimation [85]. The propensity scores are then used to match treated and control observations. Alternative matching methods include nearest neighbor (with or without replacement), kernel, caliper, and radius [86,87]. Next, balance is examined by comparing the means of the matching variables between treated and control groups. The Average Treatment Effect on the Treated (ATET) is then calculated from the mean differences between the two matched groups [88,89].

The robustness of ATET estimates to bias from unobservables is examined under the Rosenbaum Bounds Delta (Γ) framework [3,87,90]. The framework relies on the assumption of a confounding variable W that affects the likelihood of being treated. Confidence intervals (bounds) are calculated at incremental values for the effect of W on the likelihood of assignment to the treatment group. Thus, Γ is interpreted as the odds that unobservables affecting treatment status significantly bias the predicted ATET [90]. Furthermore, this framework is complimentary to the IV approach explained below because it relies on alternative assumptions to account for unobservables in the estimation procedure [90].

Five alternative PSM models are the basis to explore spillover effects from the GSP. These models incorporate the same covariates (*HH_SIZE*, *LOC*, *AGE*, *GHHH*, *EDU*, *M_STAT*, *AREA*) to generate propensity scores, and the matching algorithm selected is the nearest neighbor criterion with replacement. In the first matching estimation PSM (1), we compare *BEN* with the full control group *C_ALL*. We expect that spillover effects from the program to *C_IN* will result in downward bias of impacts in this first PSM specification. PSM (2), matches *PV* HHs with *C_OUT*, which serves as a pure control and we expect no spillover in this case. In PSM (3), *BEN* is matched with *C_OUT*, and this is the specification selected to determine the impact of GSP on the treated. PSM (4) and PSM (5) evaluate the magnitude of spillover by matching *C_IN* with *C_OUT*, and *BEN* with *C_IN*, respectively.

Before moving to results, it is important to consider another source of bias, which arises from the potential endogeneity of project participation. To address this issue we utilize instrumental variable regression (IV) that can mitigate biases from both observables and unobservables [91]. Estimation with IV requires a suitable instrument (z) that must satisfy two important conditions: (1) it must be correlated with the regressor *participation*; and (2) it must be independent of the error term [92]. A particular instrument that has been used in this context is the Intention To Treat (ITT), which is taken from the experimental medical literature [80,93,94]. Thus, ITT = 1 for eligible members of the sample regardless of *participation* (BEN) and 0 for non-eligible ones. In this case, ITT is a function of HH location in project villages, thus ITT = 1 if $PV = 1$.

IV regression is based on a two-step estimation approach [95]. In the first step, denoted in equation (iii), OLS is used to estimate participation as a function of ITT (PV) and x to get predicted *participation* $(\hat{BEN})$:

$$BEN = \alpha_{iii} + \rho PV + \beta_{iii} x + \mu_{iii} \tag{iii}$$

In the second step, a model is estimated where the predicted value of *participation* $(\hat{BEN})$ from the first step is used as a regressor. In this study, the second step model (iv) is estimated using both OLS and FR, and the OLS version is denoted as follows:

$$ADOPT = \alpha_{iv} + \tau \hat{BEN} + \beta_{iv} x + \mu_{iv} \tag{iv}$$

Post estimation results are used to determine the strength of the instrument and in cases where a single instrument is used for estimation the general rule of thumb is an F-test result greater than 10 [81,93].

4. Results

The first set of estimations are presented in Table 4 for models (i) and (ii). A total of eight models are estimated according to the alternative specifications, which include restricted (1, 3, 5, 7) and unrestricted (2, 4, 6, 8) versions of models (i) (1, 2, 5, 6) and (ii) (3, 4, 7, 8) estimated via OLS (1, 2, 3, 4) and FR (5, 6, 7, 8) (Table 4). We find the results are consistent across specifications and indicate a positive and significant impact of GSP on the adoption of HYVs by the *BEN* and *C_IN* groups relative to the pure controls denoted by *C_OUT*. Selection of a preferred model is based on various criteria. F-test results indicate that unrestricted versions are preferred to restricted ones. Model (i) is selected over model (ii) because it includes more information by estimating impact for *BEN* and *C_IN* rather than pooling these into a single *PV* group. Furthermore, we infer that the similarity in results from models (i) and (ii) is driven by spillover (Table 4). Finally, because the outcome indicator (*ADOPT*) is fractional in nature, i.e., %, FR is preferred to OLS. Thus, (6) is selected for further discussion, i.e., the unrestricted version of Model (i) estimated via FR (Table 4).

Table 4. Regression Results: Adoption of HYV Groundnuts.

	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
	(i) **OLS**$^{\mathbf{R}}$	(i) **OLS**$^{\mathbf{U}}$	(ii) **OLS**$^{\mathbf{R}}$	(ii) **OLS**$^{\mathbf{U}}$	(i) **FR**$^{\mathbf{R+}}$	(i) **FR**$^{\mathbf{U+}}$	(ii) **FR**$^{\mathbf{R+}}$	(ii) **FR**$^{\mathbf{U+}}$
BEN	0.157 *** (0.056)	0.141 *** (0.045)			0.156 *** (0.054)	0.138 *** (0.044)		
C_IN	0.158 ** (0.066)	0.137 *** (0.052)			0.157 ** (0.066)	0.139 *** (0.051)		
PV			0.158 *** (0.053)	0.140*** (0.042)			0.156 *** (0.052)	0.138 *** (0.042)
GRESP		0.0441 (0.043)		0.043 (0.043)		0.0510 (0.041)		0.0511 (0.041)
HH_SIZE		−0.005 (0.005)		−0.005 (0.005)		−0.006 (0.005)		−0.006 (0.005)
LOC_1		0.728 *** (0.077)		0.728 *** (0.077)		0.648 *** (0.067)		0.648 *** (0.067)
LOC_2		0.430 *** (0.080)		0.431 *** (0.080)		0.380 *** (0.072)		0.380 *** (0.072)
LOC_3		0.718 *** (0.078)		0.718 *** (0.078)		0.632 *** (0.069)		0.632 *** (0.069)
LOC_4		0.230 ** (0.084)		0.230 *** (0.084)		0.237 *** (0.080)		0.237 *** (0.080)
LOC_5		−0.0611 (0.080)		−0.0611 (0.080)		−0.0516 (0.081)		−0.0516 (0.081)
LOC_6		0.491 *** (0.098)		0.491 *** (0.098)		0.428 *** (0.091)		0.428 *** (0.091)
LOC_7		0.321 *** (0.079)		0.322 *** (0.079)		0.297 *** (0.072)		0.297 *** (0.072)
AGE		0.0008 (0.001)		0.0008 (0.001)		0.0007 (0.001)		0.0007 (0.001)
GHHH		0.0631 (0.068)		0.0634 (0.068)		0.0645 (0.070)		0.0644 (0.070)
EDU_1		−0.141 * (0.083)		−0.141 * (0.083)		−0.126 (0.088)		−0.126 (0.088)
EDU_2		−0.071 (0.066)		−0.071 (0.065)		−0.060 (0.071)		−0.060 (0.071)
EDU_3		−0.128 * (0.071)		−0.128* (0.071)		−0.118 (0.075)		−0.118 (0.075)
M_STAT		0.022 (0.068)		0.0221 (0.068)		0.0085 (0.072)		0.0085 (0.072)
AREA		−0.004 (0.019)		−0.004 (0.019)		−0.002 (0.018)		−0.002 (0.018)
CONST	0.405 *** (0.045)	0.052 (0.126)	0.405 *** (0.045)	0.0516 (0.126)				
R^2	0.024	0.445	0.024	0.445				
F	4.475	15.82	8.974	16.80				
n	*374*	*374*	*374*	*374*	*374*	*374*	*374*	*374*

Note: mean coefficients; standard errors (se) in parentheses; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$; $^{\mathrm{R}}$ restricted, $^{\mathrm{U}}$ unrestricted; $^{+}$ calculated average marginal effects, and se obtained by delta method.

We find that adoption of HYVs relative to *C_OUT* is +13.8% and +13.9% for *BEN* and *C_IN* respectively under (6), and the associated parameters are statistically significant at the 1% level (Table 4). The difference in *C_IN* compared to *C_OUT* is largely attributed to spillover effects from GSP. Covariate estimates indicate significant differences in adoption rates based on village location (*LOC*), which has been verified by local experts. Educational attainment of the household head (HHH) is observed to be significant at the 10% level under the unrestricted OLS PSM (2 and 4) but is not found to be the case for (6).

The estimates for the five Probit models used to examine spillover effects are included in Table 5, Figure 2 illustrates the kernel distribution of the propensity scores before and after matching, and corresponding ATET and robustness results are provided in Table 6. The probit results indicate that *AGE* (PSM 1, 3, 5) and *AREA* (PSM 2, 3, 4) are statistically significant to the estimation of propensity scores (Table 5). Figure 2 illustrates successful matching for PSM (3) with the kernel distribution in the left panel for the unmatched sample, showing the common support condition is met, and in the right panel for the matched sample with virtually complete overlap after matching. PSM (3) results are highlighted because they estimate the direct impact of GSP on adoption, revealing a +21.3% ATET with respect to HYV adoption, which is significant at the 1% level (Table 6). A Rosenbaum Bounds Delta (Γ) of 3.65 is within the acceptable range suggested by previous studies [3,87] and indicates that these results are robust to the possible influence of unobservables (Table 6). PSM (4) confirms the presence of spillover with a +14.5% difference between *C_IN* and *C_OUT* that is statistically significant at the 5% level. In addition, PSM (5) indicates that the difference between *BEN* and *C_IN* is very small and not statistically significant, which we interpret as nearly complete spillover of HYV adoption to neighbors a decade after GSP.

Table 5. Propensity Score Matching: Probit Regression Results.

	PSM (1)	**PSM (2)**	**PSM (3)**	**PSM (4)**	**PSM (5)**
	BEN/C_ALL	***PV/C_OUT***	***BEN/C_OUT***	***C_IN/C_OUT***	***BEN/C_IN***
HH_SIZE	−0.014 (0.019)	−0.004 (0.021)	−0.001 (0.024)	0.005 (0.028)	−0.018 (0.022)
LOC_1	0.187 (0.286)	0.157 (0.304)	0.291 (0.342)	0.057 (0.404)	0.068 (0.343)
LOC_2	0.387 (0.296)	0.287 (0.317)	0.477 (0.353)	0.057 (0.423)	0.264 (0.356)
LOC_3	0.147 (0.288)	0.036 (0.306)	0.176 (0.341)	−0.101 (0.415)	0.117 (0.348)
LOC_4	0.131 (0.313)	−0.205 (0.326)	0.020 (0.358)	−0.514 (0.463)	0.380 (0.406)
LOC_5	0.216 (0.295)	0.245 (0.315)	0.367 (0.353)	0.213 (0.424)	0.028 (0.351)
LOC_6	0.264 (0.360)	0.165 (0.395)	0.353 (0.436)	0.005 (0.542)	0.190 (0.428)
LOC_7	0.309 (0.290)	0.206 (0.312)	0.437 (0.351)	−0.014 (0.420)	0.203 (0.348)
AGE	0.015 *** (0.005)	0.009 (0.006)	0.016 ** (0.007)	−0.002 (0.008)	0.014 ** (0.006)
GHHH	0.0851 (0.235)	0.219 (0.254)	0.175 (0.291)	0.187 (0.331)	0.006 (0.285)
EDU_1	−0.316 (0.306)	−0.439 (0.343)	−0.508 (0.374)	−0.451 (0.478)	0.014 (0.379)
EDU_2	−0.335 (0.242)	−0.295 (0.275)	−0.402 (0.293)	−0.207 (0.386)	−0.209 (0.293)
EDU_3	−0.321 (0.262)	−0.465 (0.292)	−0.531 * (0.311)	−0.531 (0.417)	−0.059 (0.321)

Table 5. *Cont.*

	PSM (1)	PSM (2)	PSM (3)	PSM (4)	PSM (5)
	BEN/C_ALL	*PV/C_OUT*	*BEN/C_OUT*	*C_IN/C_OUT*	*BEN/C_IN*
M_STAT	−0.238	−0.346	−0.401	−0.241	−0.113
	(0.253)	(0.286)	(0.314)	(0.383)	(0.304)
AREA	−0.063	−0.171 **	−0.159 **	−0.240 **	0.091
	(0.028)	(0.029)	(0.032)	(0.046)	(0.039)
CONSTANT	−0.266	0.847 *	0.221	0.759	−0.130
	(0.447)	(0.497)	(0.555)	(0.672)	(0.531)
n	*374*	*374*	*289*	*183*	*276*

Note: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$; se in parentheses.

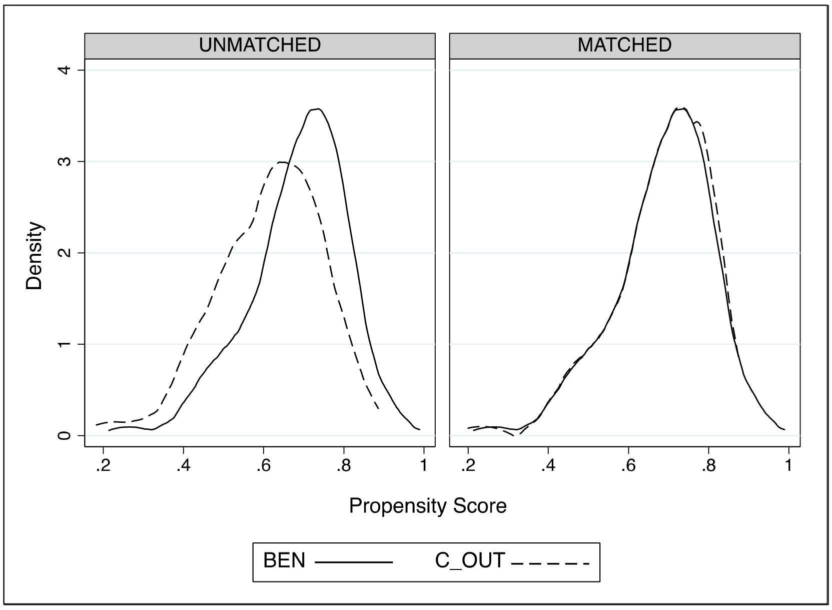

Figure 2. Kernel distribution of propensity scores from PSM (3): unmatched and matched samples.

Table 6. Average Treatment Effect on the Treated and Rosenbaum Bounds Estimates.

	PSM (1)	PSM (2)	PSM (3)	PSM (4)	PSM (5)
	BEN/C_ALL	*PV/C_OUT*	*BEN/C_OUT*	*C_IN/C_OUT*	*BEN/C_IN*
ATET	0.051	0.037	0.213 ***	0.145 **	−0.025
	(0.056)	(0.061)	(0.072)	(0.065)	(0.063)
Rosenbaum Bounds Delta (Γ)	1.90 $^{+}$	1.85 $^{+}$	3.65 $^{+}$	3.55 $^{+}$	1.75 $^{-}$

Note: ** $p < 0.05$, *** $p < 0.01$; se in parentheses; Rosenbaum bounds delta significance level, $p < 0.01$: $^{+}$ upper bound, $^{-}$ lower bound.

IV regression results are presented in Table 7 and indicate that GSP impact is greater than initial estimates from alternative specifications of models (i) and (ii), when we control for bias from unobservables. The F-test statistic from IV(1) first stage post-estimation of 13.4 indicates that ITT is a strong instrument (Table 7). Second stage IV estimates for GSP outcomes differ slightly between OLS (IV(2a)) and FR (IV(2b)) models with mean impact on HYV adoption of +21.1% and +22.3%, respectively, both of which are significant at the 1% level (Table 7). These results are consistent with the PSM (3) ATET estimate of +21.3% (Table 6). This consistency in results from alternative methodologies, i.e., PSM and IV, is evidence that our findings are robust and we can say with confidence that after a decade GSP had a +21% impact on HYV adoption relative to control HHs. Furthermore, this translates to an average of nearly 60% of groundnut area allocated to HYVs among GSP participants.

Table 7. Instrumental Variables Regression: Intention to Treat (ITT).

	IV(1)	**IV(2a)**	**IV(2b)**
	(*iii*) 1st Stage	**(*iv*) 2nd Stage: OLS**	**(*iv*) 2nd Stage: FR $^+$**
PV	0.656 *** (0.0489)		
BEN		0.213 *** (0.066)	0.211 *** (0.063)
GRESP	−0.138 ** (0.049)	0.073 (0.047)	0.080 * (0.045)
HH_SIZE	−0.004 (0.006)	−0.005 (0.005)	−0.005 (0.005)
LOC_1	0.013 (0.089)	0.725 *** (0.080)	0.645 *** (0.067)
LOC_2	0.098 (0.092)	0.410 *** (0.083)	0.359 *** (0.073)
LOC_3	0.026 (0.090)	0.713 *** (0.081)	0.626 *** (0.069)
LOC_4	0.079 (0.097)	0.213 ** (0.087)	0.220 *** (0.079)
LOC_5	0.010 (0.091)	−0.063 (0.082)	−0.054 (0.081)
LOC_6	0.038 (0.112)	0.483 *** (0.101)	0.420 *** (0.091)
LOC_7	0.080 (0.090)	0.305 *** (0.081)	0.280 *** (0.072)
AGE	0.004 ** (0.002)	−2.0e-5 (0.002)	−1.0e-4 (0.001)
GHHH	0.065 (0.078)	0.049 (0.070)	0.051 (0.071)
EDU_1	−0.049 (0.095)	−0.131 (0.086)	−0.116 (0.089)
EDU_2	−0.069 (0.075)	−0.056 (0.068)	−0.045 (0.072)
EDU_3	−0.030 (0.082)	−0.122 * (0.073)	−0.112 (0.075)
M_STAT	−0.032 (0.078)	0.029 (0.070)	0.015 (0.072)
AREA	0.019 (0.022)	−0.008 (0.019)	−0.006 (0.018)
CONSTANT	−0.124 (0.145)	0.078 (0.127)	
R^2 F	0.402 14.06	0.413 15.89	
n	*374*	*374*	*374*

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$; se in parentheses; $^+$ calculated average marginal effects, and se's obtained by delta method.

5. Discussion

This work complements a number of recent studies of groundnut producers in Uganda by considering the sustainability of GSP outcomes regarding adoption of HYVs over a period of 10 years following the end of the intervention [3,5,7,8,62]. Our analysis of sustainability is two-fold: (1) lasting impact on adoption levels among participants; and (2) diffusion of adoption to neighboring HHs beyond the direct scope of the project via spillover effects. We find a consistent +21% difference in HYV adoption levels between HHs that participated in the program and those that did not, after controlling for bias from observables and unobservables. Spillover effects are revealed by differences in adoption outcomes between participants, a control group composed of neighbors, and another control group consisting of farmers from non-participating villages.

Spillover effects are worthwhile to consider when designing future programs as a beneficial approach to the dissemination of program benefits, and additional research is needed to examine the practicality and cost-effectiveness of this mechanism. Ultimately, extension-based efforts are essential to facilitate adoption and to link research and development (R&D) with growers via the continuous exchange of information among key stakeholders. Based on an earlier report, the ATU program functioned as a primary link between stakeholders and resulted in HYV uptake during the GSP period [13]. We find that adoption increased primarily for a single variety (Serenut 2), which remains popular because of seed saving practices. We infer that once GSP ended, adoption stagnated and newer varieties have been largely ignored by farmers because of limited availability in the markets and access to capital to purchase seed. A decade later, yields for HYVs are low compared to results from recent experimental trials, which is likely due to limited access to quality seed and saving beyond the recommended number of growing seasons.

Approaches to enhance food security and create resilient food systems are multifarious and rely on insights from a diverse set of stakeholders. The complexity of achieving sustainable food systems has become more evident as we contend with an increasingly global society, particularly in SSA where long-standing challenges persist [96]. Moreover, sustainable development initiatives are critical to achieve long-term development goals [47]. We find that among the many studies that have examined HYV adoption, limited attention has been given to the long view. Therefore, our study offers a novel contribution to the literature by considering the legacy of project impacts to smallholders.

Our primary goal in conducting this analysis was to examine whether or not adoption of HYVs increased among GSP participants and their neighbors; we then consider the following extensions to our main research question; were appropriate complimentary practices to adoption used in order to ensure that higher yields were achieved over time and did the project result in greater food security through higher yields, and by extension increased HH income. We found that adoption did increase; furthermore, yields were highest among beneficiaries (by variety), indicating successful adoption of complementary growing practices and by extension increases in HH food supply; however, over the period following GSP, yield declined for the predominant HYV variety (Serenut 2). This unexpected result was partly due to the fact that additional knowledge of recommended seed acquisition practices was not effectively delivered to participants during training; consequently, farmers saved seeds for multiple seasons leading to loss of parent genetics. We thus infer that had GSP effectively demonstrated the importance of the cycles of adoption and the appropriate seed saving practices, yields would have been greater over the long-term, resulting in sustainable increases in food security among participants. To sum up, GSP was effective at increasing adoption, but only resulted in short-term increases in yields. Future research should address appropriate training programs needed to achieve long lasting results.

We see the potential for adoption to be successful over long periods of time, and look forward to results of research that builds on these findings to include training on seed saving practices in future projects so that these HHs can benefit from higher yield and a sustainable increase in food security. Important research extensions include access to capital for seed purchases, e.g., microcredit, and availability of genetically pure seeds.

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