



Public–private partnership generates economic benefits to smallholder bean growers in Uganda

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Abstract

The quest to transform and hasten the role of smallholder farms in agricultural development and food security through farmer–firm linkages has dominated development interventions in low-income countries for several decades. This has mostly been pursued through single- or multi-contract schemes implemented in isolation. Several studies have analyzed the effects of these schemes on smallholder farms with mixed results. A new paradigm is to use Agricultural Public Private Partnership (Ag-PPP) to achieve wider and sustainable impacts. However, limited empirical evidence exists on the effects of Ag-PPP interventions and targeting the same farmer. We address this research gap by assessing the impact of an Ag-PPP on small-scale common bean producers in Uganda. We use a doubly robust difference-in-difference approach in a multi-treatment setting to estimate these impacts. The results show that the PPP created positive outcomes for farmers and stimulated increased production from targeted interventions. Evidence shows that the PPP and its interventions were associated with significant increases in productivity, sales volumes, and shares of output marketed. Receiving bundled interventions had greater effects than a single intervention and effects varied between men and women bean crop owners. Results suggest that providing bundled interventions through a PPP can increase productivity and alleviate market access constraints. The outcomes of this Ag-PPP could be modified for other contexts i.e., crops and localities, to inform food and development policy elsewhere.

Keywords Ag-PPP · Productivity · Market participation · Revenues · Bean production · Uganda

JEL Classification D13 · O22 · O30 · Q12

1 Introduction

One component of food security is food availability which consists of three elements: production, allocation, and exchange. To achieve these elements, the production, and productivity of staple crops, for example common beans in east and central Africa, must increase and market failures that hinder trade must be addressed to ensure that excess production moves from the farm to locations where food is critically needed. Productivity growth and strategic market integration are thus important pathways to food security in farming systems that are dominated by smallholder farmers (World Bank, 2007). Food must also be transformed and made available in a form that sustainably serves the needs of both rural and urban consumers (Augustin et al., 2016; Knorr et al., 2020). Required interventions to achieve these outcomes include developing productivity enhancing agricultural technologies, technology transfer to farmers, building the capacity of farmers to use these technologies, linking

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producers to markets, and food processing and supply. Single scheme interventions including market contracts, resource-providing contracts, knowledge transfer, and promotion of new crop technologies among others have partly worked to deliver these outcomes but an approach such as a Public Private Partnership (PPP) that leverages wider resources and capabilities could have greater impacts. The PPP (the CultiAf-Ag-PPP) assessed in this paper was designed to match these needs. Public private partnerships if used both strategically and tactically can improve global food security (Smyth et al., 2021).

Agricultural-Public Private Partnerships (Ag-PPPs) are increasingly being promoted as a systematic institutional innovation for bridging the resource gaps that often constrain the public sector from realizing the agricultural potential in reducing poverty and promoting food and nutrition security in the developing world (Hermans et al., 2019). According to the FAO (2016), an Ag-PPP (or a PPP) is formed by bringing together public institutions, private businesses, and civil society into a formalized partnership designed to meet specific sustainable agricultural development objectives. The objective of the public sector in this partnership is the socio-economic transformation of the society; achieved by leveraging resources within the private sector to deliver public benefits including to the poorer households. The objective is achieved by creating incentives for private investment and the inclusion of smallholders. On the other hand, private partners join partnerships to reduce risks and transaction costs where market failures would otherwise constrain their profit maximization objective and thus business growth. These objectives form the basis of defining benefits, investment contributions, and risk sharing so that active roles exist for all partners at various stages throughout the PPP lifecycle. Agricultural PPPs recognize the value of integrating research into the multi-stakeholder platform to address multiple challenges that would otherwise stand in the way of success.

Thus, PPPs bring together actors and allow them to provide services in what they do best and manage risk appropriately (FAO, 2016; Menezes et al., 2018; Weirowski & Hall, 2008). This is important in situations where the public sector is resource and expertise constrained. Agricultural PPPs in agrarian societies where the agricultural sector plays a predominant role have commonly been used in technology transfer and value chain development to accelerate agricultural productivity growth, commercialization, income generation, food security, and subsequently improve people's welfare (FAO, 2016).

Until recently, agricultural development programs for food security, commercialization, income, and poverty eradication in low-income countries, have been pursued through farmer agribusiness linkages (Aragie et al., 2016; Carletto et al., 2017). These linkages, among smallholder farmers,

take the forms of production contracts, market contracts, resource-providing contracts, and knowledge enhancing interventions among others (Danso-Abbeam et al., 2018; Hoang et al., 2021; Otsuka et al., 2016; Ruml & Qaim, 2020). Although promoting farmer linkage with agribusiness firms comes with multiple benefits (Norell et al., 2015; Ochieng et al., 2019), they do so with risks given that agribusiness firms also face production risks that could be transferable to farmer. The PPPs can spread these risks by building synergies and identifying the expertise of different actors to minimize the effects of occurrence (FAO, 2016). Once risk is spread, productivity is raised, and food supply grows, and the rationale for food self-sufficiency gives way to portfolio diversification including market integration—the long-run goal of such interventions (Fafchamps, 1992).

Agricultural PPPs have been used extensively (FAO, 2016; Hermans et al., 2019) but there is limited empirical analysis regarding their impacts on agricultural development and smallholder farms. Consequently, there is a dearth of information on whether or not and how they contribute to agricultural growth and economic development, which is the goal for which they are promoted. Previous literature mostly based on qualitative, and to a lesser extent quantitative, analysis has documented benefits of Ag-PPP on farmer gross annual incomes, daily wage rates, employment, access to land and credit, food security, and technical knowledge in Africa and Asia (FAO, 2013a, b, 2016).

Various studies have analyzed the effects of subcomponents of PPPs such as single scheme contracts/interventions on small scale farmers (Danso-Abbeam et al., 2018; Hoang et al., 2021; Mohamed, 2008; Nzomo & Muturi, 2014; Otsuka et al., 2016; Wordofa & Sassi, 2017). These showed varied impacts on farmer incomes, production efficiency, technology adoption, farmer access to agricultural credit, and enhanced knowledge. A few studies have examined a multi-contract scheme approach that targets the same farmers (Ashraf et al., 2009; Mishra et al., 2016). Ruml and Qaim (2020) analyzed the effect of marketing and resource-providing contracts when implemented in one scheme. They found that resource-providing contracts increased farmers' input intensity, productivity, and scale of production while market contracts have no significant effect on input use and productivity. Limited literature has examined contracts that involve multiple actors implementing the some kind of interventions at the same time (Ragasa et al., 2018).

These studies analyzed single or multi contract schemes implemented in isolation, leaving a research gap in empirical evidence for interventions implemented as a package by multiple actors through a PPP setting and targeting the same farmer. Here, we address this research gap using a more rigorous empirical strategy to assess the impact of the CultiAf-Ag-PPP, with multiple packages, on farm productivity and commercialization (measured by volumes and share

of farm output marketed) among common bean producers in Uganda. The CultiAf-Ag-PPP bundled and deployed interventions as a package through a PPP arrangement for larger gains. The packages to bean farmers included: seed credit, knowledge transfer, and a market contract. Beans were purchased to be processed and sold in the Ugandan and Kenyan market.

Common bean was chosen because it is a staple and the most important legume crop grown (by 80% of farmers) and consumed in Uganda (Anderson et al., 2016). For the last five years, an average of 510,156 hectares of beans was grown annually with estimated mean output of 846,383 tons in Uganda (FAO, 2022). The crop plays a significant role in household food and nutrition security in Uganda and the East and Central African (ECA) region at large. Uganda's national per capita consumption of beans is estimated at 9.8 kg (Larochelle et al., 2016), while that for other East African countries (western Kenya, Rwanda, Burundi) is the highest in the world ranging between 48–60 kg per person per year (Broughton et al., 2003; Ochieng et al., 2014). Uganda is a net exporter of beans in the east and central African region.

In Uganda, beans contribute an average of 14.4 g of protein per person per day in rural areas, an equivalent of 24% of the total daily per capita protein intake (Larochelle et al., 2017). Biofortified beans, which were part of the bean types promoted by the CultiAf-Ag-PPP, have been proved to enhance micronutrient (Iron and Zinc) content and bio-availability among bean consumers (De Moura et al., 2014; Finkelstein et al., 2017; Glahn et al., 2017). The crop is also becoming an important cash crop in Uganda and is quickly gaining significance due to its potential for value-added production, and a crop for nutrition-sensitive value chains.¹ However, low productivity due to limited access to improved bean technologies because of weak seed systems, and a poorly coordinated value chain, limits the volume of preferred varieties available for consumption and processing.

The CultiAf-Ag-PPP sought to solve this challenge to increase the production and supply of nutrient-rich bean varieties suitable for processing into pre-cooked beans to make them readily available on the market. This was to be achieved through coordinated roles while leveraging experiences and resources of various actors: processors, a seed company, non-governmental organizations, farmers, and researchers, as elaborated below in Sect. 2. Farmers in rural hamlets had the opportunity to tap into and benefit from both up and downstream services offered by the partnership.

¹ The beans bred and promoted are high in Iron and Zinc and other micronutrients. They are also an excellent source of proteins, carbohydrates, and fiber.

Using a Doubly Robust Difference in Difference (DRDID) framework (Sant'Anna & Zhao, 2020), the study examines the economic benefits to farmers when given production guarantees, seed credit, capacity building, and market support. Findings show that being part of the PPP is associated with positive outcomes for farmers and stimulated increased production from targeted interventions. The study documents evidence of a significant increase in sale volumes and shares, thus sales revenue due to increases in bean productivity. These benefits varied between men and women and within gender categories. From these insights the study draws lessons that can inform practitioners on how to introduce new linkages to a rural society with small-scale farmers.

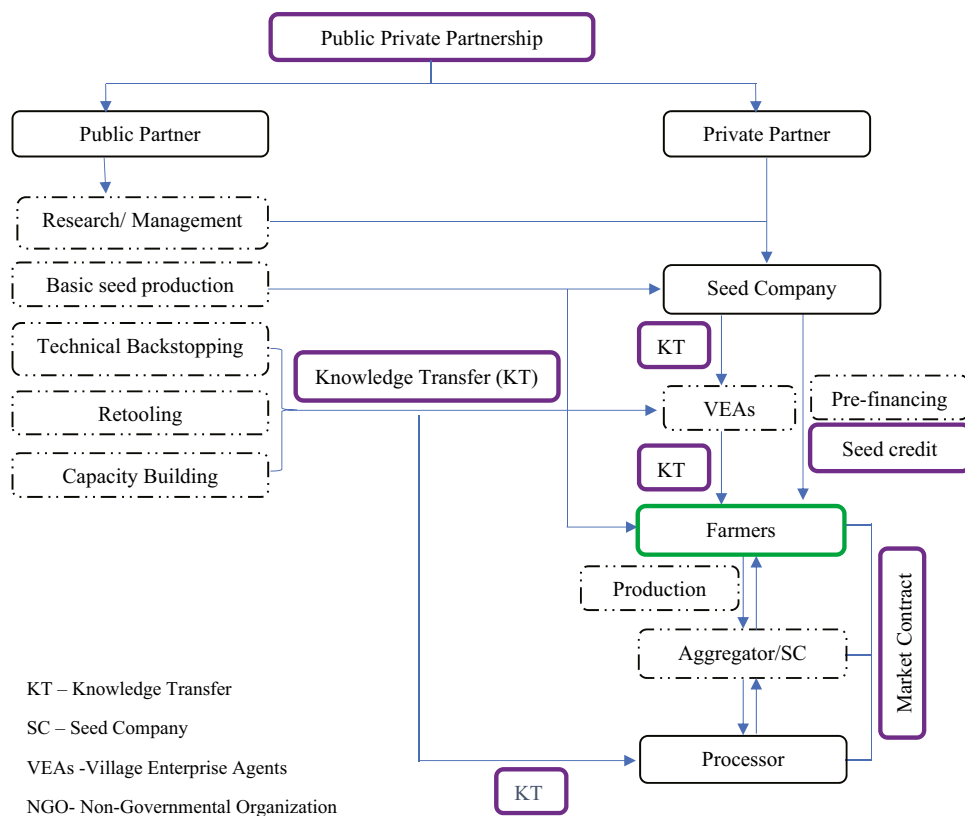
In the following section, we present background information on the Ag-PPP, including its operationalization, interventions, and partners. Section three describes the data, study area, sampling strategy, and data balance check. Section four presents the empirical strategy and estimation methods while section five describes and discusses the results. Section six offers policy implications and conclusions.

2 CultiAf-Ag-PPP intervention synopsis

The Ugandan Agricultural Research Organization has developed several bean varieties with high-quality processing traits. This has encouraged bean processing into precooked bean products, and flour as a raw product for developing snacks, soups, or porridge as the new end uses of bean grains. However, expansion of bean processing is constrained by the lack of sufficient volumes of quality bean for processing in associated value chains due to poorly coordinated bean supply chains. The adoption of improved research-derived bean varieties with processing qualities remains critically low because of weak seed dissemination systems that are characterized by low public funding and uncertain seed demand. For example, the formal sector that supplies seed of improved bean varieties only contributes 12% of seed supply with local seed businesses and agro-dealers/seed companies being the main suppliers (Mugisha et al., 2020). The private seed companies have strong established networks for delivering improved variety seed but they are constrained by uncertainty in seed demand, the high risk of investing in new innovations, and the high costs of multiplying and supplying new improved seed at a wide scale. To bridge these gaps, the CultiAF-Ag-PPP was initiated in 2015 with the ultimate goal of accelerating the diffusion of improved varieties for increased production and supply of bean types suitable for processing.

Figure 1 depicts the structure of the PPP, the players involved, and their roles. To stimulate and expand seed

Fig. 1 The structure of the CultiAf-Ag-PPP, type of partners, roles and nature of interventions. Note: The components evaluated by the study are highlighted in bold solid boxes. Dotted boxes show services offered by actors in the PPP. Farmers were up and down stream beneficiaries of PPP



production and dissemination, Uganda's National Agricultural Research Organization (NARO) — a public sector actor supplied foundation bean seed for the production of certified and quality-declared seed, to the Community Enterprises Development Organization (CEDO). This aimed to subsidize the cost of seed production to enable CEDO to offer seed credit. CEDO is a private sector actor that supports agro-enterprise development including production and marketing capacity of the local communities through supplying high quality seeds in Uganda. Seed credit was meant to ease access to quality seed of improved bean varieties by reducing liquidity constraints to seed access among farmers. The varieties supplied were those similar to farmer-preferred varieties to hasten variety acceptance. NARO managed the partnership at the national level and led national research. It also conducted face-to-face training for farmers and Village Enterprise Agents (VEAs)² in good agronomic practices. Training in gender issues of bean production and marketing was also offered to ensure inclusivity. Certified and quality declared bean seed supply, community monitoring, and aggregation services were offered by the CEDO.

² Village Enterprise Agents (VEAs) are village-based extension agents (could be drawn from experienced farmers in villages) who work directly with farmers and support them by creating systems that facilitate access to diverse types of information: production, output and input markets among others.

Lasting Solutions Limited (a private partner) processed beans into pre-cooked beans which guaranteed a market, as a purchaser of produced beans, to farmers. A guaranteed market by the processor removed demand uncertainty for bean producers while at the same time ensuring supply for the processor. A pre-negotiated price kept the partner buyer more competitive while offering an incentive to farmers to supply. This pre-negotiated price was such that it was higher (by at least 200 UGX per Kg) than the prevailing market price at the time of marketing.³ Also, farmers who needed prefinancing were supported with cash to reduce the possibility of side selling before beans were picked by the aggregator (CEDO). Without access to this competitive market, productivity gains from these innovations would mean little. Through research supported by NARO, the product processor also received technical support in product development. This reduced the cost of developing product prototypes. The Center for International Tropical Agriculture and the Pan Africa Bean Research Alliance managed and coordinated partnership research at regional and international levels.

³ To reduce buyer and farmer price uncertainty, the aggregator capped the price at 2000 UGX/Kg of beans. This amount was based on the market price of beans that ranged between 1600–1800 UGX/Kg in project sites and was often higher than prevailing market prices.

The project integrated research within an innovation system that included all stakeholders of the bean value chain. The processors were the final consumers of grain and farmers the primary actors at the first node of the chain. Stakeholders in the bean value chain included: processors, a seed company, farmers, and researchers. The PPP offered multiple packages and guarantees to farmers and other actors involved. Thus, the CultiAf-Ag-PPP was a business model designed to create a sustainable and self-managing intervention.

(A) PPP interventions, treatments, impact pathways, and outcomes

The CultiAf-Ag-PPP introduced new varieties bundled with information on good agricultural practices while creating an enabling environment with seed credit, market incentives, and risk management to facilitate adoption. Notable features (treatments) of the CultiAf-Ag-PPP to farmers included: Ag-PPP membership, Market contracts, Seed Credit, and Knowledge Transfer (Fig. 1). Membership to the CultiAf-Ag-PPP in this study was defined as being part of the PPP farmer groups (by assignment), and or on top of receiving PPP intervention packages. Being in this group is thus based on the initial treatment assignment and essentially captures the intent to treat. Farmers in the PPP were provided with numerous opportunities, including: (1) attendance at PPP meetings, (2) interaction with partners, (3) benefits from monitoring, learning, and evaluation visits, and recommendations, and (4) participation in demonstrations. These nonpecuniary benefits, of Ag-PPP membership, have been found to impact farmer behavior, farm activities, and performance (Howley, 2015).

While the Ag-PPP introduced different transfers and all farmers in the selected groups had an opportunity to take part in the PPP and choose from the various packages, farmers were free to select into the intervention(s) that they were interested in. As such, there was variation among participating farmers with regards to the package of intervention(s) received, with some receiving bundled interventions. This allowed for the separate analysis of the impact of receipt of each intervention on targeted outcomes. Because farmers were free to select into a given transfer, the PPP can be split by nature of package thus, multilevel PPP treatments.

The PPP offered *market contracts*, including a competitive market to farmers for their produce, intended to remove marketing bottlenecks and incentivize production. Farmers were offered higher prices relative to prevailing market prices, prefinancing to farmers who desired it, and supported with product aggregation. This was necessary because the bean market is lucrative, and the marketing window is short, yet processing required large bean volumes. Farmer groups aggregated their produce at one collection point and ensured

that members maintained quality requirements. Because group aggregation made farmers assume some costs from aggregators, higher prices served as compensation for the value-added and enhanced efficiency in marketing. Payment for products was made through the farmer group, which was then paid to members. For farmers who received seed credit, the cost of seed was deducted before paying for products.

The *Seed Credit package* offered seed credit of improved bean varieties selected from a menu of high nutrient varieties. The seed credit was offered in kind so that credit could not be used for other purposes other than direct sowing. The processor prescreened and selected twelve varieties for promotion. These were high in iron and zinc, which ensured that farmers were exposed to nutritious beans for home consumption. The farmer group served as the guarantor (via social capital) for the seed credit received by its members. In total, approximately 982.5 tons of bean seeds were supplied to 13,503 farmers in four seasons of the first phase of the PPP (2015 to 2017). Farmers under the PPP received training in various Good Agronomic Practices (GAP)⁴ in common bean production, collective marketing, post-harvest handling, records and financial management, food and nutrition security, and safe handling of chemical inputs. This *Knowledge Transfer* benefited 13,772 farmers, of which 59.5% were women. Selected model farmers received additional training as village enterprise agents (VEAs) and Trainers of Trainers (TOTs). These farmers received training in leadership and gender in bean production and marketing, post-harvest handling, variety maintenance, east African community grain standards, and innovation platform involvement and management. The VEAs supported day-to-day extension activities among project farmers and functioned as local contacts in villages. They also served as aggregator agents of produce on behalf of the buyer.

We summarize the impact pathway in Table 1. Through the various interventions, the CultiAf-Ag-PPP aimed to improve the welfare of bean farming households. This would be realized through farming-practice and behavioral change for those farmers who were targeted. The expected outcome at plot level was higher productivity, which would increase the volume and share of bean grain available for sale. This ultimately would enhance the incomes and food security of beneficiary farmers.

(B) Selection of farmers for the CultiAf-Ag-PPP

The CultiAf-Ag-PPP selected farmer groups, but not farmers, that directly benefited from program interventions. First,

⁴ GAP included: pest and disease management, soil fertility management, weed management, variety choice and maintenance, and plant spacing.

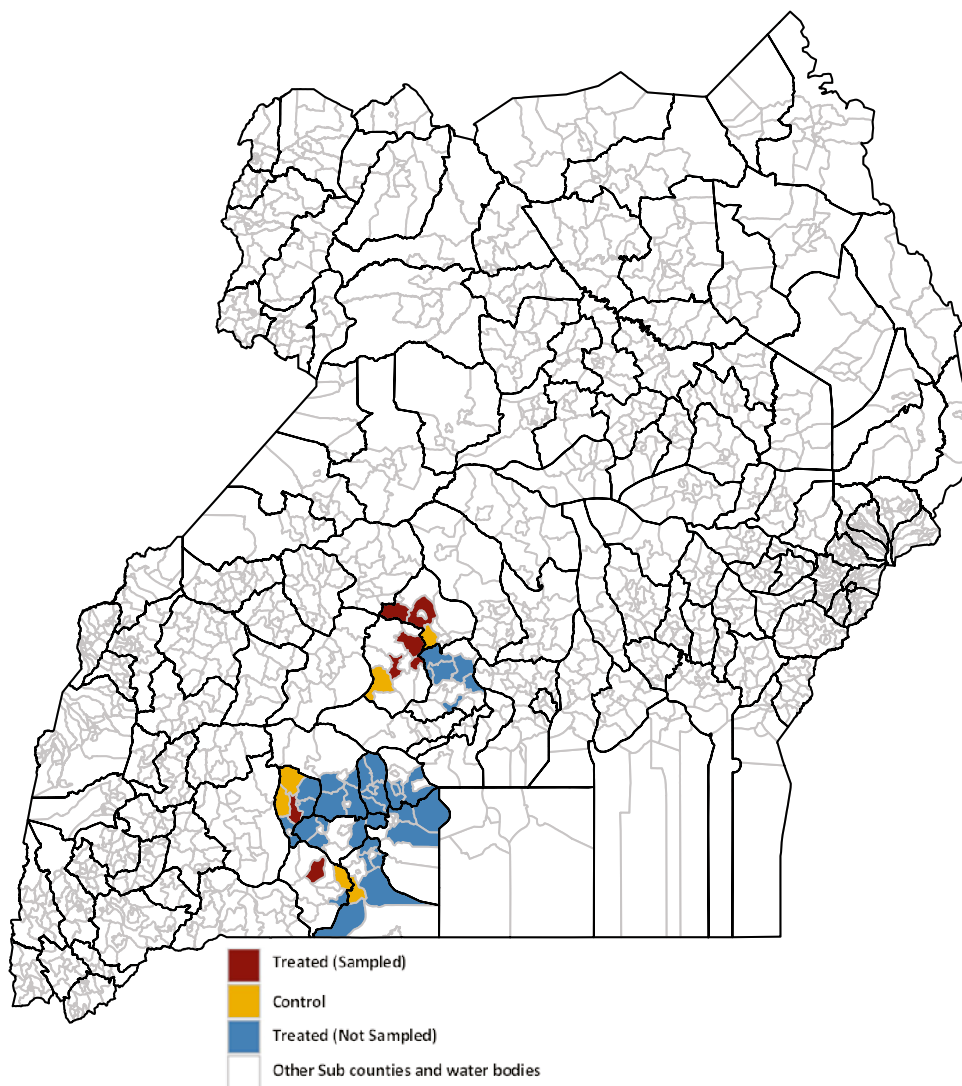
Table 1 Summary of Ag-PPP Impact pathways and outcomes

Intervention	Output	Outcomes	Impact (Higher level outcomes) measure
Knowledge Transfer	Access to knowledge	Adoption of some production and management techniques	Changes in per unit area productivity (Kg/Ha) and higher production (Kgs)
Seed credit	Access to seed of improved varieties	Adoption of improved varieties and use of quality seeds	Changes in per unit area productivity (Kg/Ha) and higher production
Market contract	Access to a competitive bean market	Improved access to competitive markets	Changes in per unit area sales (Kg/Ha) Change in share of bean output out of total production sold

ten districts in the East African bean corridor: Rakai, Masaka, Lwengo, Lyatonde, Bukomansibi, Sembabule and Kalungu in greater Masaka; and Mubende, Kiboga, and Mityana in greater Mubende in Fig. 2 were purposively selected because they are major bean growing districts in the bean corridor of Uganda. Then, with the guidance of district production and extension staff, two sub-counties per district were selected to take part in the project, based on their levels of and suitability

for bean production. For the selected sub-counties, production staff guided the choice of farmer groups from a list of available groups within the sub-county. The choice criteria for farmer groups were: (1) it should have been registered at sub-county, district, or national level, (2) had a formal management structure, (3) should have a constitution or governing laws/regulations, and (4) had at least some members actively involved in bean production. Following this

Fig. 2 Map of Uganda showing the Location of intervention districts and the study sample. Source: Authors using R



criterion, a total of 490 mixed producer farmer groups with 19,220 (9615 male and 9605 female) farmers were selected. A section of these groups was profiled Nakazi et al. (2017a) to ascertain the status of the groups. All the farmers growing the common bean in these groups had opportunities to access any of the interventions offered by the PPP.

3 Data, study area, and descriptive statistics

3.1 Sampling strategy

The data used in this study is based on data from four rounds of surveys collected by and in partnership with the National Crops Resources Research Institute of NARO. The surveys aimed to elicit information from both participating and non-participating farmers. The study focused on farming households because they benefited from both upstream and downstream services offered by the partnership. To arrive at the sample of participating farmers for the study: (1) four intervention districts (out of 10 participating districts) were randomly selected, (2) from the selected districts, the two participating sub-counties (Fig. 2), and a pool of farmer groups, at least four farmer groups were randomly selected per sub-county. In total, data was collected from 41 farmer groups and at least 5–6 farmers per group. In the steps that followed, information on the selected farmer groups, including the number of farmers and villages of residence was used. Farmer group leaders and VEAs developed the lists of farmers in each group. Using the list of farmers in selected farmer groups and a random starting point, a method (K + 1) was used to select farmers to be interviewed. Every k^{th} member on the list was interviewed to ensure randomization in the choice of the sample within the farmer group.

To obtain the counterfactual, non-participating farmers were randomly selected from participating districts, but non-partnership sub-counties (Fig. 2). Here, the study used separation by geographical location to motivate identification which implicitly invoked the Stable Unit Treatment Value Assumption (SUTVA). However, the study met an issue with this assignment, since some farmers in intervention groups were spread across different sub-counties. It was possible to find a few farmers living in a nonparticipating sub-county but belonging to a participating farmers' group with a majority of members in the participating sub-county. This could have led to 'contamination' of the sample and could have likely increased indirect exposure. However, we assume that this overlap did not affect the direction of effects in the results of this study and thus the results remain internally valid. Specifically, farmers were disaggregated based on their initial treatment status, reducing the possibility of contamination. The sampling procedure adopted at the baseline determined the sampling of farmers in all subsequent survey rounds since the study tracked the same farmers.

Following this procedure, a total of 553 bean-growing households were interviewed in the first/baseline round by NARO, in 2016 (2015 production data) in Lyatonde, Rakai, Kiboga, and Mubende, 445 households in the second round (2016 production), and 431 in the third round (2018 production) and 241 in the fourth round (2019 production) in the same districts. The study followed the same farmers through all stages of the study.⁵ However, there were high attrition rates for the last round of data collection because it was conducted by telephone interviews⁶ yet some phone numbers provided by farmers were not available/out of service, some farmers refused to take the survey on phone, 42 had no phones but tracked through VEAs, and two had died. We developed a panel attrition weight using variables that we assumed remained constant over time: head gender, years of formal schooling and birth year and use it as a weight in our empirical estimation.

Household and market characteristics data (household size, education level, age, and sex of the head, belonging to a farmers group, crop ownership, and bean price) was collected at household level while yield and area data were collected at plot level.⁷ Where households had multiple bean plots, the study considered all bean plots and we calculated bean output as the total dry bean harvest (fresh bean harvest was converted to the dry bean equivalent) while area was the total area cultivated (Ha) by the household. In total 198 of the sampled households benefited from the seed credit, 169 benefited from the market contracts and 207 benefited from the knowledge transfer. Also, some households benefited from bundled treatments: seed credit and market (159), seed credit and knowledge (167), market and knowledge (144) and seed-market-knowledge (140). Data for the study was collected by a team of trained enumerators using Computer Assisted Personal Interviewing (CAPI) techniques.

3.2 Balance check and baseline statistics

The study used the Difference in Difference (DID) approach. One key identifying assumption for the DID model is that trends in the outcome variables would have been the same

⁵ After accounting for missing values in some variables and the fact the preferred model (DRDID) requires that each household must be observed more than once in the study, the effective sample used for model estimation was 1270 such that the effective sample size in each year was: 2015 production data=388; 2016 production data=413; 2018 production data=242; and 2019 production data=227.

⁶ Telephone interviews were selected as a substitute for face-to-face interviews because of total lock down restrictions impose to curb the spread of COVID-19. These restrictions limited movement of public and private cars, and thus access to farmers.

⁷ The number of bean plots were: 2015 production season=810; 2016 production season=612; 2018 production season=509; and 2019 production season 304 bean plots.

Table 2 Balance check and Baseline summary statistics of outcome variables and covariates

Variables	Baseline Treated group (n = 240)		Baseline control group (n = 313)		PPP membership (n = 553)		Seed credit (n = 553)		Market Contract (n = 553)		Knowledge Transfer (n = 553)	
	Mean	SD	Mean	SD	Coef.	p-val.	Coef.	p-val.	Coef.	p-val.	Coef.	p-val.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Outcome variables												
Productivity (Kg/hectare)	854.20	578.46	885.50	740.44	-31.299	0.624	14.765	0.875	-88.901	0.125	8.415	0.902
Amount sold (Kg/Ha)	658.12	545.47	657.58	644.61	0.543	0.992	35.120	0.688	-105.222	0.052	42.802	0.506
Share of bean output sold	0.72	0.23	0.68	0.24	0.040	0.103	0.033	0.257	-0.061	0.075	0.047	0.070
Farming/market characteristics												
Area planted (hectare)	0.71	1.22	0.52	0.37	0.182	0.034	0.131	0.098	0.371	0.233	0.113	0.107
Price (T UGX/Kg)	1.45	0.43	1.48	0.37	-0.029	0.550	0.219	0.031	-0.070	0.450	0.100	0.036
Household characteristics												
Household size (No. Members)	6.19	2.53	0.52	0.50	0.183	0.334	0.069	0.853	-0.061	0.856	0.174	0.503
Education level (1 = Post primary)	0.25	0.44	0.22	0.42	0.031	0.405	-0.052	0.347	-0.010	0.871	-0.000	0.999
Average age of head	46.75	13.14	44.55	12.09	2.202	0.120	-0.180	0.935	2.811	0.167	-1.529	1.527
Belongs to farmer group (1 = Yes)	0.93	0.26	0.30	0.46	0.628	0.000	0.324	0.000	0.323	0.000	0.475	0.000
Sex of head (1 = male)	0.74	0.44	0.62	0.49	0.114	0.015	0.190	0.001	0.150	0.012	0.114	0.037
Crop ownership (1 = Female)	0.45	0.50	0.54	0.50	-0.090	0.047	-0.153	0.027	-0.128	0.041	-0.156	0.017

Columns 2 to 5 show the baseline statistics of the sample. Columns 6 and 7 show the results of OLS regression comparing households selected for the project and those in the control group. Columns 8 to 13 are OLS estimates comparing outcomes for groups of farmers that benefited from different transfers/interventions compared to the control at the baseline. The number of treated households per category was: PPP membership = 240; Seed credit = 63; market contract = 57; and knowledge transfer = 114. The regressions included constants that are not reported here. All standard errors are clustered at the village level

in both groups in the absence of PPP interventions (the Parallel Trends Assumption (PTA)). Thus, any differences in the two groups in the post-intervention period, when other exogenous covariates are controlled for, can be assumed to be associated with the PPP or its interventions. The study could not verify the PTA since we did not have data on the two groups pretreatment. However, the study conducted a ‘balance check,’ the other key identifying assumption that outcomes of the two groups should be similar pretreatment. The study compared farmers assigned to the PPP/benefited from PPP interventions and those that did not at the baseline. If the similarity assumption holds, then there would be no significant differences in means of targeted PPP outcomes pre-treatment.

We used a generic bivariate regression (Eq. 1) with errors clustered at the village level for the balance check to compare means of outcome variables of treatment groups at the baseline.

$$Y_i = \alpha + \varnothing D_i + \varepsilon_i \quad (1)$$

⁸ Essentially, one would assume zero receipts for interventions at the baseline, but a few farmers reported to have received interventions similar to some of PPP interventions. These receipts were however not based on the PPP framework.

where α is the intercept, ε is a summary random variable that represents all other causes of Y_i . The variable Y_i includes the outcome variables of the PPP: productivity, volume of marketed output, and share of output marketed out of production. Here, D_i represents a bivariate variable assigned to PPP or having benefited from one or more of its interventions in the year before the PPP.⁸ The coefficient estimate \varnothing is the naïve estimator of the relationship between D and Y (Morgan & Winship, 2014). It is a measure of the difference between the sample means of observed outcome Y for farmers in the PPP/received intervention and the control group at the baseline. The assumptions here include: our sample is large enough to run comparisons, sampling error components of the regression error have zero conditional means, and there is no measurement error in predictors.

Table 2, shows the results of this balance check. For outcome variables, Columns 6 to 13 of Table 2 shows that households assigned to the PPP and PPP intervention packages, and the control group are similar in all outcome variables at the baseline ($p > 0.05$). This confirms that the outcomes in the two groups were similar pretreatment. Table 2, Columns 2 to 5 show the summary statistics (mean and standard deviation) of the baseline sample for the treated and control groups. An average farmer’s productivity was 854 and 885 kg/ha for the treated and control groups, respectively, lower than previous literature. Estimates based on

FAO (2020) and UBOS (2019) show that the average yield of dry beans in Uganda between 2007 and 2018 ranged between 1.2 to 1.6 tons/ha, while potential yields of newly released/improved bush common bean varieties was 1.8–2.5 tons/ha (TASAI, 2016). Commercialization levels among sampled bean farmers were also fairly high averaging 68%, with farmers in both groups selling an average of 658 kg/ha.

For farm and household characteristics, the sample in the treated and control group was different for the following characteristics: belonging to the farmer group and sex of the head and crop owner (Table 2). Also, PPP members were different in acreage cropped while seed credit and knowledge intervention recipients were paid different prices for their beans. Households were similar in all other characteristics. Although only trends and observed patterns in targeted outcomes are important for identification in DID, conditioning on pre-treatment covariates, that are assumed to be constant overtime, in DID is key for satisfying the PTA (Sant’Anna & Zhao, 2020).

4 Identification and estimation

The study’s empirical strategy exploits the variation in farmer yields and output allocation to assess the impact of the CultiAf-Ag-PPP. To model PPP impacts, the study uses the doubly robust difference in difference (DRDID) approach proposed by (Sant’Anna & Zhao, 2020). The DRDID estimand identifies the Average Treatment effect on the Treated (ATT) even if one of the models (the propensity score or outcome model) are misspecified (Sant’Anna & Zhao, 2020). This is a great improvement over models that use the difference in difference and propensity score models separately. Also, this is important for our case because we did not have a way of verifying the PTA, yet conditioning on pre-treatment covariates in DID is assumed to satisfy PTA (Sant’Anna & Zhao, 2020).

In this study, there are two treatment periods (the pre-treatment period $t = 0$ and post treatment period $t = 1$) and two treatment groups ($D_{it} = 1$ if household i is treated before time t and $D_{it} = 0$ otherwise). Our treatments include: Being a PPP member, benefiting from (1) seed credit, (2) a market contract, (3) knowledge transfer, and (4) bundled treatments (Seed credit– Market contract, Seed credit– Knowledge transfer, and Market contract– Knowledge Transfer). The total sample, n , is $n_0 + n_1$, where n_1 and n_0 are the sample sizes of the post-treatment and pre-treatment periods.

Let Y_{it} be one of the outcome variables of interest for a bean farming household i at time t . In this study there are three outcome variables: (1) bean productivity (Kg/hectare), (2) volume of bean marketed (Kg/hectare), and (3) the share of bean production marketed. The potential outcome notation allows us to state the realized outcome equation as $Y_{it} = D_i Y_{it}(1) + (1 - D_i) Y_{it}(0)$. In the regression framework,

a vector of pre-treatment covariates X_i can be added to aid identification. In our model, X_i includes sex of the household head, level of education of the head, year of birth of the head, whether the head belongs to a farmers group. Following (Abadie, 2005; Sant’Anna & Zhao, 2020), we assume that X_i is constant over time. Furthermore, we assume that the data are independently and identically distributed (iid). With these assumptions, the ATT, which is our parameter of interest, τ , is given by $\tau = \mathbb{E}[Y_{i1}(1) - Y_{i0}(0)|D_i = 1]$. Unless exclusion causes confusion, we have dropped the i subscript to ease notation in subsequent equations.

Following Sant’Anna and Zhao, (2020) (check the article for a detailed derivation of the model) our estimator for the ATT in a panel data setting is given by:

$$\hat{\tau}^{dr,p} = \mathbb{E}_n \left[(\hat{w}_1^p(D) - \hat{w}_0^p(D, X; \hat{\gamma})) (\Delta Y - \mu_{0,\Delta}^p(X; \hat{\beta}_{0,0}^p, \hat{\beta}_{0,1}^p)) \right], \tag{2}$$

where: $\hat{w}_1^p(D) = \frac{D}{\mathbb{E}_n[D]}$, $\hat{w}_0^p(D, X; \hat{\gamma}) = \frac{\pi(X;\gamma)(1-D)}{1-\pi(X;\gamma)} / \mathbb{E}_n \left[\frac{\pi(X;\gamma)(1-D)}{1-\pi(X;\gamma)} \right]$, $\mathbb{E}[\cdot]$ is the generic expectation notation, p is the true unknown propensity score, $\Delta Y = Y_1 - Y_0$, $\pi(\cdot)$ is the arbitrary model for the true, unknown propensity score with its parameters γ , $\mu(\cdot)$ is the model for the true, unknown outcome regression with its parameters β , and $w_1^p(\cdot)$ and $w_0^p(\cdot)$ are weighting functions, chosen by the researcher, for the treated and untreated groups respectively.

Because the choice to participate in PPP interventions and the associated errors between the equations may be correlated, we evaluated the possibility of error independence across equations and found significant positive correlations in the three equations (Table 7, Appendix A). This provided the reason for DID systems estimation of the intervention equations, to produce smaller standard errors and to check the robustness of our estimates. We used the Seemingly-Unrelated Regressions (SUR) framework for this estimation, thus DID in SUR. Also, we found some sample contamination where 42 non-PPP farmers, spread across study rounds and treatments, reported receipt of Ag-PPP treatments. We therefore estimate a DID model that accounts for neighborhood effects to aid identification. We follow the approach proposed by Clarke, (2017) by adding the effect of being an indirect beneficiary. The added variable $R(i, t)$ is defined as a binary variable that takes a value of 1 if the individual was an indirect beneficiary of the PPP and 0 otherwise. Since the treatment occurs only in period 1, $R(i, 0) = 0$. Here, θ , is the effect of being an indirect beneficiary and δ is an initial fixed effect of being in the group of indirect beneficiaries. Thus, the DID model of the systems estimation approach is

$$Y_{mi,t} = \alpha_0 + \alpha_1 Time_{mi} + \alpha_2 PPPintervention_{mi} + \theta Time_{mi} \cdot PPPintervention_{mi} + \delta R(i, t) + \vartheta R(i, t) \cdot PPPintervention + X' \gamma + \epsilon_{mi,t}, m = 1, \dots, M \tag{3}$$

where $Y_{mi,t}$ is the PPP outcome for household i at time t , m is the equation number used to represent different regression equations. There were three equations, one for each Ag PPP package and is estimated for each of the three outcome variables. The parameter α_1 captures round/time fixed effects (in DID the time trend in the control group), $PPP_{intervention_i}$ is a dummy that denotes whether a household participated in the partnership (1 = participated) with α_2 being its parameter. Essentially, α_2 captures the difference between the partnership and non-partnership groups pre-intervention. In Eq. (3), the coefficient θ is the DID parameter of interest and can be interpreted as the difference in changes over time. The variable X is a vector of pre-treatment covariates similar to those used in Eq. (2).

The study also conducted an analysis by gender of the crop owner⁹ because women dominate the production and marketing of common beans in Uganda (Nakazi et al., 2017b; Njuki et al., 2011) and bean is traditionally regarded a “women’s crop” (Njuki et al., 2011). It is therefore important that program interventions on a crop like beans ensure that women are fully integrated to streamline gender in production, distribution, and consumption activities. Also, bean being a crop typically grown by women means that women are better placed to promote it for better food, nutrition, and income gains. Adding a gender disaggregated analysis was important because the program aimed to include both genders in all aspects of bean production and marketing to ensure that women farmers were not marginalized and that gains from PPP interventions were equitably distributed across gender categories. Knowledge from such analysis can be used to promote more gender based, sensitive, and targeted interventions. The study investigated the role of gender by: (1) disaggregating households based on the gender of the crop owner and (2) adding an interaction term between each treatment and gender of the crop owner in Eq. (3).¹⁰

5 Results

Results of the main model – DRDID model and estimates based on the DID systems approach are presented in what follows. The impact of each of the interventions is discussed alongside the impact of the overall CultiAf-Ag-PPP

intervention. Revenues from bean sales are highly correlated with productivity, so we chose to present only results of the productivity analysis and base on these to draw inference and implications for household bean revenues. The study also uses productivity and income gains to draw implications on household food security. We discuss only the results of the DRDID model in our presentation of results, unless there were interesting contrasts from the systems DID model.

5.1 Impact of the public–private partnership and interventions on farmers’ productivity

Doubly robust DID estimates for participation in the CultiAf-Ag-PPP reveal that farmer participation in the PPP was associated with about 29% higher yields (210 kg/Ha) compared to those not in the partnership (Table 3, Column 2). The effect stays significant and positive, with a lower effect, even when we estimate the model as a system (Table 3, column 6). Furthermore, the study finds that each of the interventions positively contributed to increased farmer productivity. The market contract (Table 3, Column 4) had the highest effect on bean productivity and was associated with an increase in productivity of 250 kg/Ha (35%) for farmers who benefited from the intervention over nonbeneficiaries. Furthermore, farmers who benefited from seed credit were likely to report 158 kg/Ha higher yields relative to farmers who did not receive seed credit. Receiving the knowledge transfer was associated with on average yield advantage of 34% (247 kg/Ha) compared to not receiving the knowledge transfer. Overall, the effect of participation in the PPP or any of its transfers was associated with a 22% to 35% increase in productivity relative to non-participation/not benefiting. Receiving a bundled intervention was associated with even high productivity gains (Table 4).

Given that productivity was highly correlated with revenues, these interventions could have a revenue enhancing effect among bean farmers. Moreover, beans are the main legume (staple) consumed by households in the study area, thus increasing productivity could also increase food and nutrition security through consumption of iron and zinc rich bean types. Productivity gains from adopting improved bean varieties have been shown to improve household food security outcomes (Katungi et al., 2018; Letaa et al., 2020). Table 8 shows the effect of having indirect beneficiaries on productivity. This effect is positive and significant for seed credit receipt suggesting that having indirect beneficiaries could be associated a productivity increase of 25 kg/Ha. While the effect is negative for the market contract and knowledge transfer, the net effect does not wipe out the productivity gains from the market and knowledge PPP interventions.

⁹ A crop owner is defined here as that person in the household that predominantly manages the bean crop and also has rights to determine how the crop will be utilized.

¹⁰ We present comparisons based on DID systems estimates since in the DRDID model the interaction term was dropped due to multicollinearity.

Table 3 Impact (ATT) of the public–private partnership on farmers’ outcomes: DRDID and systems approach estimates

	Control group mean (sd)	PPP Member	Seed credit	Market contract	Knowledge Transfer	PPP Member ^a	Seed credit	Market contract	Knowledge Transfer
PPP outcome	DRDID					DID in SUR			
	1	2	3	4	5	6	7	8	9
Productivity (Kg/Ha)	720.680 (520.301)	209.513*** (54.056)	157.932** (80.887)	249.929** (97.069)	247.344*** (50.691)	129.317** (68.818)	314.601*** (3.502)	159.369*** (11.137)	106.514*** (3.324)
Bean output sold (Kg/Ha)	517.472 (464.079)	168.120*** (50.451)	106.960 (77.136)	233.625*** (93.364)	162.190 (47.123)	122.156** (61.439)	325.441*** (2.852)	104.305*** (12.387)	91.575*** (2.672)
Share of bean output sold	0.642 (0.279)	0.028 (0.030)	0.025 (0.038)	0.096** (0.041)	0.024 (0.026)	0.043 (0.001)	0.027*** (0.001)	0.011*** (0.003)	-0.040*** (0.002)
District dummies		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Other covariates		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
No. observations		1270	1270	1270	1270	1270	1270	1270	1270

Controls: household head sex, education of head, age of head, and farmer group membership. Columns 6 to 9 are based on Seemingly Unrelated Regression (SUR) in a panel setting. Control group mean is the average for each outcome over all periods

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

^aThe analysis is based on linear regression absorbing district fixed effects

5.2 The impact of public–private partnership and interventions on farmers’ market outcomes

We tracked two market outcomes: the volume of beans (Kg) marketed per hectare and the share of bean output out of total production (Kilograms sold divided by kilograms produced) that the household marketed. The study finds that

participation in the partnership was associated with selling 168 kg/Ha (about 33%) higher output than being a nonmember (Table 3, Column 2). For interventions, by guaranteeing a competitive market for all produce, farmers were likely to report selling 234 kg/Ha (45%) higher bean output compared to their counterparts without a guaranteed market (Table 3, Column 4). While the effects stay positive, they were not

Table 4 Impact (ATT) of receipt of bundled intervention packages on targeted PPP outcomes

	Control group mean	Seed credit –Market contract	Market –Knowledge Transfer	Seed credit –Knowledge Transfer	Seed credit –Market Contract	Market –Knowledge Transfer	Seed credit – Knowledge Transfer
PPP outcome	DRDID				DID in SUR		
	1	2	3	4	6	7	8
Productivity (Kg/Ha)	720.68 (520.30)	601.899*** (190.714)	666.302*** (163.095)	307.363*** (85.859)	695.091*** (9.581)	211.955*** (24.339)	149.758*** (5.203)
Bean output sold (Kg/Ha)	517.47 (464.08)	471.265*** (179.653)	644.529*** (166.670)	263.620*** (83.612)	627.489*** (8.746)	130.717*** (25.260)	69.322*** (4.817)
Share of bean output sold	0.64 (0.28)	0.005 (0.073)	0.169** (0.076)	0.092* (0.048)	0.044*** (0.001)	0.028*** (0.005)	0.140*** (0.001)
District dummies		Yes	Yes	Yes	Yes	Yes	Yes
Other covariates		Yes	Yes	Yes	Yes	Yes	Yes
No. observations		1270	1270	1270	1270	1270	1270

Standard errors are in parentheses

The model is controlled for household head sex, education of head, birth year, and farmer group membership. All models were estimated with district dummies. Results in column 6 to 8 are based on seemingly unrelated regression in a panel setting. Control group mean is the average for each outcome over all periods

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

Table 5 Impact of the public–private partnership on men and women: DiD systems coefficient estimates of gender by treatment dummy interaction

Outcome	Pooled average	PPP Membership ^a	Seed credit	Market contract	Knowledge Transfer	Seed credit –Market contract	Market –Knowledge Transfer	Seed credit –Knowledge Transfer
		1	2	3	4	5	6	7
Productivity (Kg/Ha)	786.90 (568.86)	69.602 (62.739)	118.464*** (2.848)	2.276 (7.754)	29.575*** (3.293)	163.730*** (3.451)	52.044*** (10.616)	32.530*** (2.893)
Bean output sold (Kg/Ha)	588.75 (529.86)	67.741 (56.031)	98.843*** (1.771)	29.719** (12.963)	65.163*** (1.975)	134.618*** (3.099)	28.737** (11.676)	7.651*** (2.729)
Share of bean output sold	0.68 (0.26)	0.029 (0.029)	0.061*** (0.002)	0.016*** (0.006)	0.030*** (0.001)	0.057*** (0.001)	0.037*** (0.005)	0.041*** (0.001)

Number of observations = 1270. Standard errors are in parentheses

The model is controlled for household head sex, education of head, age of head, and farmer group membership. All models were estimated with district dummies. In crop owner dummy, male = 1 and 0 otherwise

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

^aThe analysis is based on linear regression absorbing district fixed effects

significant for the seed credit and knowledge transfer. However, when farmers received seed credit and knowledge coupled with the market contract, the effects were significant (Table 4). For example, a beneficiary of both seed credit and market contract, was likely to report selling 471 kg (91%) higher bean volumes offered for sale than those that did not receive any of the two transfers (Table 4, Column 2). Being a recipient of bundled PPP interventions was also associated with higher and significant effects on volumes of output marketed. Except for the market contract and market-knowledge transfer, other PPP interventions did not have significant effects associated with the share of bean output marketed by farmers, both singly and when the farmer received interventions as a bundle. The market contract and when it is bundled with the knowledge transfer were associated with 15% and 26% higher share of bean output allocated for sale, respectively, by beneficiaries than non-beneficiaries. The DIDSUR estimates show positive and significant effects associated with all interventions except receipt of the knowledge transfer which was negative and significant (Tables 3 and 4). A negative effect meant that PPP households were allocating more beans for household consumption than for the market, compared to non-PPP households. Having indirect beneficiaries has the same effect on volumes of beans sold as that observed for productivity, whilst the effect is positive for seed credit and market contract for the share of bean output marketed (Table 8).

The results demonstrate that the Ag-PPP and its programs had positive effects on farmer productivity and marketed output. Importantly, offering an assured market leads to higher gains compared to other interventions. In such rural settings, access to markets and market services, due to high transaction costs and market failures, is often an important

bottleneck that farmers face (Key et al., 2000; Nichterlein, 2011). By guaranteeing a competitive market at a price higher than the prevailing market price, farmers are likely to respond with increased production. Cascading effects are therefore likely since each of the outcomes reinforces another. For example, higher productivity leads to more output available for sale and as more are sold, farmers earn higher revenues per hectare cultivated. If incomes earned are used on food purchases as often is the case (Larochelle et al., 2016), this could also have a positive effect on household food security.

Findings in this study provide evidence that corroborates previous studies that have shown that innovative delivery of extension, improved technologies, and market services to farmers is important for enhancing productivity, revenues, and food security (Hoang et al., 2021; Katungi et al., 2018; Letaa et al., 2020; Nakano et al., 2018; Otsuka et al., 2016; Todo & Takahashi, 2013). Also, improved market access has been shown to increase farm productivity, by facilitating specialization, crop choice, and intensification in different parts of the world (Gafaro & Pellegrina, 2018; Kamara, 2004; Oppen et al., 1997).

5.3 Crop owner gender disaggregated analysis of the impact of the public–private partnership and its interventions

Because bean is considered a women's crop, given women dominance in the production of the crop, an intervention that changes production and marketing dynamics of the crop could have different effects on men and women. Here, we thought to analyze the effect of various PPP interventions on women and men taking into account: (1) within gender comparisons

Table 6 Impact (ATT) of the public–private partnership: DiD systems estimates disaggregated by gender of crop owner

Outcome	Control group mean	PPP Membership ^a	Seed credit	Market contract	Knowledge Transfer	Seed credit –Market contract	Market –Knowledge Transfer	Seed credit –Knowledge Transfer
Panel 1		1	2	3	4	5	6	7
Productivity (Kg/Ha)	687.48 (475.18)	12.654 (96.144)	294.949*** (12.040)	60.818*** (16.264)	4.140 (8.264)	166.596 *** (32.069)	31.634 (26.246)	24.322** (10.241)
Bean output sold (Kg/Ha)	489.46 (421.46)	15.648 (84.152)	168.515*** (15.558)	32.699** (14.988)	-44.610*** (14.637)	287.859*** (26.454)	8.965 (21.794)	6.690 (8.749)
Share of bean output sold	0.64 (0.28)	0.072 (0.046)	-0.031*** (0.009)	0.225*** (0.009)	-0.079 *** (0.002)	0.173*** (0.015)	-0.014 (0.019)	-0.113*** (0.006)
Panel 2		Man owned crop (n = 745)						
Productivity (Kg/Ha)	747.61 (553.49)	203.857** (97.201)	3.114 (8.747)	54.992*** (12.050)	135.590*** (6.059)	231.491*** (14.348)	105.416*** (16.112)	186.776*** (7.509)
Bean output sold (Kg/Ha)	540.19 (495.47)	133.969 (86.326)	-117.235*** (8.309)	49.399*** (11.574)	76.024*** (6.141)	127.670*** (10.426)	33.665*** (12.176)	75.797*** (5.286)
Share of bean output sold	0.65 (0.28)	0.006 (0.042)	0.001 (0.005)	0.059*** (0.007)	0.035*** (0.004)	0.006 (0.005)	0.021*** (0.005)	0.049*** (0.002)

Standard errors are in parentheses

The model is controlled for household head sex, education of head, birth year, and farmer group membership. All models were estimated with district dummies

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

^aThe analysis is based on linear regression absorbing district fixed effects

(women and men beneficiaries and non-beneficiaries) and (2) between gender comparisons (between women and men).

To check the between-gender effects of crop ownership and PPP interventions on PPP outcomes, we added an interaction term between crop ownership and receipt of a PPP treatment. We find that for productivity, receipt of seed credit, the knowledge transfer, and all bundled interventions was associated with a positive effect for male crop owners (Table 5). For example, the additional effect of being a male crop owner and receipt of seed credit was 118 kg/Ha higher productivity. Similarly, for the volume of beans sold and the share of beans allocated to the market, having access to all PPP interventions including bundled interventions was associated with positive and significant effects on male crop owners. These findings suggest a need for interventions that are more targeted towards women. While the PPP took this into account during implementation, there is more that needs to be done in terms of intervention targeting and structuring of PPP processes to include and equitably benefit men and women. For example, in most cases, bean aggregation during marketing was done and managed by men which could have reduced the observed benefits for women as some women feared exposing their earnings from beans sales. Also, men largely manned aggregation centers. Additionally, women allocating a smaller share of their bean harvest to the market corroborates the fact that women have an extra home care role and the desire to ensure household food security.

For within gender comparisons, women receipt of seed credit was associated with the highest effected of 295 kg/Ha (about 43%) higher yields compared to women that did not receive seed credit (Table 6, Panel 1). We also found positive effects on productivity for being part of the market a contract. The productivity effect of receiving seed credit combined with a market contract and seed credit and knowledge transfer was also positive for women that benefited, showing higher gains than their counterparts. Seed credit and market contracts were associated with increased volume of beans sold for PPP women than non-PPP women. The knowledge transfer was associated with a reduction in the volume and share of beans that PPP women sold compared to non-beneficiaries. This is not surprising since the project placed serious emphasis on household food security¹¹ over marketing during capacity building sessions. The negative effect of seed credit on marketed share could be attributed to the fact that women in some cases saved and used own saved seed in some seasons. This was done to save on the cost of seed. Also, for women beneficiaries, the knowledge transfer was associated with a negative and significant association with the share of output marketed. This is likely because

¹¹ Farmers were encouraged to reserve sufficient quantities of beans for home use and only sell surplus production and or produce beans for both the project and for home use whenever possible.

women in the developing world have a homecare role where they have to produce and allocate some of the production to meet home food needs (McKenna, 2014; Quisumbing et al., 1996; Visser & Wangu, 2021). Since the knowledge transfer encouraged farmers to sell only when they had excess production over home needs, this is a positive result for food security sensitive households.

Like the effect on women, men who benefited from the different project interventions were more likely to report higher productivity than their male counterparts that never benefited (Table 6, Panel 2). Being a male PPP member was also associated with positive gains in productivity compared to non-beneficiaries. The negative effect on volumes sold and the non-significant effect on share of beans allocated to the market associated with seed credit could be because male farmers also recycled bean seed in the bid to cut the cost of seed. The net effect is however positive and significant when seed credit is combined with the knowledge transfer or a market contract. As opposed to the situation seen for women, the knowledge transfer was not associated with a lower share of beans sold among PPP men compared to non-PPP men. Even with food security knowledge, men have been observed to be more market oriented. Also, since the PPP had a higher positive effect among men than women (Table 5), it is likely they had higher volumes to sell.

6 Discussion and policy implications

This study's results provide evidence of the benefits to farmers of using PPPs to promote innovations that increase production, productivity, market participation, and food security. This research analyzed the economic benefits created by an Ag-PPP with multiple intervention packages among farming households in a rural setting. Ag-PPPs are being promoted for improving productivity and driving pro-poor growth in the agriculture and food sectors of the developing world. This has spurred funding of programs with cross-cutting approaches aimed at achieving wider impacts. The study findings show that by leveraging on its potential to create synergies, the CultiAf-Ag-PPP created positive outcomes for bean farming household and stimulated increased production from targeted interventions. Each component (seed credit, market contracts, and knowledge) of the PPP played different roles in contributing to production and market outcomes. As such, the study shows how a PPP can lead to positive impacts when well designed and managed.

The market contract created the largest change in productivity (increasing productivity by up to 35%), marketed output (by 45%) and share of output allocated to the market by 10% among the different transfers while the knowledge transfer and seed credit boosted productivity by 34% and 22%, respectively. Farmers who bundled these interventions received much high benefits compared to non-beneficiaries. The observed effects varied by gender and highlight the

need for gender focused and sensitive interventions for a women's crop like beans. Findings imply that a PPP can be a good platform for fostering production, increasing sales volumes and shares, and strengthening a local value chain. When productivity gains are linked to market participation thus household income, food expenditures, and food supply and availability, PPP interventions could also contribute to household food security. Documentation of international experiences, benefits and case studies on the performance of different PPPs is provided by (FAO, 2016; Menezes et al., 2018; Weirowski & Hall, 2008).

For an Ag-PPP to be successful at the farm level, PPP actors should endeavor to identify critical control points and actions that curb deviations from normal operation at each point in time. Even though farmers are downstream beneficiaries, critical actions aimed at creating win-win scenarios should be identified at the initiation of the PPP to the operationalization and evaluation of interventions. These should access actions and operations of all upstream actors that are likely to impede the path to a successful PPP and corrective actions must be taken promptly. Thorough due diligence, clear role identification and allocation, managing expectations, and roll-out plans need to be put in place at the conceptualization stage. This should be followed by creating a communication strategy that facilitates information sharing between actors to ensure transparency and awareness. Whenever necessary, clear contracts and memorandums of understanding should be put in place to guide operations. Also, for the successful implementation of Ag-PPP interventions at the local level, community social norms need to be reflected and respected and local leadership should be involved in operations.

When modified for other contexts i.e., crops and localities, the nature of this Ag-PPP program can inform food and development policy elsewhere. Single scheme interventions have been widely implemented in low-income countries with varying levels of success (Hoang et al., 2021; Mohamed, 2008; Otsuka et al., 2016). Adopting and adapting such programs to fit the PPP framework could have higher and wider impacts. While the CultiAf-Ag-PPP tried to incorporate sustainability, catalyzing better opportunities for the main players, our concern is whether the knowledge gained will push actors, especially farmers, to explore, grow, and sustain impacts at scale. This study did not examine the impact of the PPP on profitability/net income of the bean enterprise because data on production costs was lacking. Therefore, future research that could seek to track the PPP beyond the program phase to evaluate sustainability issues and effect on net income. Additional future research could seek to investigate the impact of such an Ag-PPP after the passage of time to measure program efficacy, its impacts, and welfare changes among farmers as the time of exposure changes. Finally, there is a need to conduct a cost benefit analysis of such a programme to ascertain the return on investments both for the public and private sector.

Appendix A

Table 7 Correlation analysis for residual independence in treatment equations estimated as seemingly unrelated regressions

Treatment	Seed credit	Market transfer	Knowledge transfer	X ² (p-value)
Outcome: Productivity (Kg/Ha)				
Seed credit	1.000			4479.947 (0.000)
Market contract	0.996	1.000		
Knowledge transfer	0.997	0.995	1.000	
Outcome: Bean output (Kg) sold per hectare				
Seed credit	1.000			4771.540 (0.000)
Market contract	0.995	1.000		
Knowledge transfer	0.997	0.993	1.000	
Outcome: Share of bean output sold				
Seed credit	1.000			4739.828 (0.000)
Market contract	0.991	1.000		
Knowledge transfer	0.994	0.989	1.000	

Table 8 Coefficient estimates for the indirect beneficiary dummy and interaction

		PPP Member [†]	Seed credit	Market contract	Knowledge Transfer
Productivity (Kg/Ha)	δ	32.633 (71.771)	24.846*** (3.187)	-47.194*** (11.137)	-91.848*** (4.083)
	θ	Na	-52.414*** (5.041)	-3.501 (12.886)	67.515*** (5.632)
Bean output sold (Kg/Ha)	δ	32.878 (58.437)	48.800*** (2.604)	-60.982*** (8.751)	-109.519*** (3.307)
	θ	Na	-70.031*** (4.137)	-23.230 (14.199)	63.989*** (4.604)
Share of bean output sold	δ	0.072** (0.032)	0.046*** (0.002)	0.028*** (0.003)	-0.002 (0.002)
	θ	Na	-0.038*** (0.002)	-0.030*** (0.004)	-0.013*** (0.002)

Estimates are from Eq. (3) for additional terms added to control for the possibility of indirect beneficiaries. Na implies that the parameter θ is not estimated because the treatment occurs with certainty in t=0

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Data availability Data that support findings of this study are available from authors upon reasonable request.

Declarations

Competing interests The authors declare that they do not have any competing interests.

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