IMPACT OF CASSAVA INNOVATIONS ON HOUSEHOLD PRODUCTIVITY AND WELFARE IN UGANDA

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This research programme was carried out in collaboration with the Department of Agricultural Economics of the University of Pretoria, South Africa, the Agricultural Development Economics Division- Impact Evaluation of UN FAO, Rome, Italy and National Crops Resources Research Institute of Uganda

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DECLARATION

I certify that the work contained in this thesis, or any part of it, has not been accepted in substance for any previous degree awarded to me, and is not concurrently being submitted for any degree other than that of Doctor of Philosophy being studied at the University of Greenwich. I also declare that this work is the result of my own investigations, except where otherwise identified by references and that the contents are not the outcome of any form of research misconduct.

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DEDICATION

To my family

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ABSTRACT

Agriculture remains the mainstay of Uganda's economy, employing its majority population and contributing significantly to its GDP. Cassava is a national priority crop for Uganda and remains a globally competitive source of food, nutrition and income security as well as an industrial commodity due to its unique attributes. However, its productivity remains inadequate due to low technology uptake, dysfunctional seed systems, poor farmer organisation and policy failures.

Motivated by several problematized research gaps, this study carried out an empirical investigation to answer seven research questions: (a) what are the causal determinants of participation in cassava Agricultural Innovation System (AIS) initiatives? (b) what is the impact of participation in cassava AIS interventions on cassava productivity and household welfare? (c) what are the causal factors influencing the choice of cassava seed access sources? (d) what are the determinants of cassava technology adoption? (e) what is the impact of improved-uncertified cassava seed adoption on cassava productivity and household welfare? (f) what is the impact of improved-certified cassava seed adoption on cassava productivity and household welfare? (g) do different impact estimation strategies yield consistent impact estimates? This study used cassava stem and root yield as measures of productivity while household welfare was measured using cassava cash income and household total consumption expenditure both adjusted to per capita levels using Adult Equivalent Units. The results indicate that educated households and those that belong to other forms of farmer groups were more likely to join AIS initiatives than their less educated counterparts and those that do not belong to other groups. Propensity Score Matching results reveal that participation in AIS initiatives enhances cassava productivity and household welfare outcomes. Agricultural Innovation Platform (AIP) members were more likely to adopt production enhancing inputs such as improved certified seed. Promotion of AIS approaches is advised. Farmer perceptions about the use of improved certified seed and seed sources, household decision-making and input access shocks influence farmers' choice of a given seed source. It is recommended that both state and non-state actors should fund decentralized cassava seed multiplication centers. AIP membership, access to extension services, land size, education, family size, and age of the household head are some of the causal determinants of adoption and adoption intensity of cassava technologies. The study also obtained consistent results from Ordinary Least Squares, PSM and Endogenous Switching Regression that use of improved certified cassava seed is productivity- and welfare-enhancing. Finally, the study has contributed to knowledge by providing one of the first sets of empirical evidence to support spousal roles in household decision-making, use of AIS concepts in technology promotion, importance of seed inspection and certification programmes in Uganda. The study has also contributed to the knowledge and literature on impact of agricultural technology adoption by extending robust methodologies to the previously neglected but all-important cassava commodity.

***Key words*:** Agricultural Innovation Systems, Agricultural technology adoption, cassava innovations, adoption and adoption intensity determinants, productivity and welfare impact, Two-Part model, probit model, Propensity Score Matching, Endogenous switching Regression, Uganda

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ACRONYMNS

ACDP	Agriculture Cluster Development Project
AEU	Adult Equivalent Units
AIP	Agricultural Innovation Platforms
AIS	Agricultural Innovation Systems
ATE	Average Treatment Effect
ATT	Average Treatment Effect on the treated
ATU	Average Treatment Effect on the untreated
CAADP	Comprehensive African Agricultural Development Programme
CBSD	Cassava Brown Streak Disease
CIA	Conditional Independent Assumption
CMB	Cassava Mosaic Disease
CSEs	Cassava Seed Entrepreneurs
DFID	Department for International Development of the United Kingdom
DRC	Democratic Republic of Congo
ESR	Endogenous Switching Regression
ESRM	Endogenous Switching Regression Model
FAO	Food and Agriculture Organization of the United Nations
FARA	Forum for Agricultural Research in Africa
FGD	Focused Group Discussion
FGT	Foster Greer Thorbecke (Poverty Line)
FIML	Full Information Maximum Likelihood
GDP	Gross Domestic Product
GPS	Global Positioning Device
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IDRC	International Development Research Center
IFPRI	International Food Policy Research Institute
JML	Joint Multinomial Logit Model
KBM	Kernel-Based Matching
KII	Key Informant Interviews
LR	Likelihood Ratio
LSMS-ISA	Living Standards Measurement Surveys –Integrated Surveys in
MAAIF	Ministry of Agriculture, Animal Industry and Fisheries
MEU	Man Equivalent Unit
MFPED	Ministry of Finance, Planning and Economic Development
MNL	Multinomial Logit Model
MPS	Mean Plot Size
MT	Metric Tones
NAADS	National Agricultural Advisory Services
NaCRRI	National Crops Resources Research Institute
NARO	National Agricultural Research Organization
NDP	National Development Programme
NEPAD	New Economic Partnership for Africa's Development
NGO	Non-Governmental Organization
NIE	New Institutional Economics
NNM	Nearest Neighbor Matching
NRI	Natural Resources Institute

NSCS	National Seed Certification Services
OLS	Ordinary Least Squares
OWC	Operation Wealth Creation
PAD	Project Appraisal Document
PS	Propensity Score
PSM	Propensity Score Matching
RUM	Random Utility Model
SSA	Sub-Saharan Africa
TC	Transaction Costs
TLUs	Tropical Livestock Units
TT	Treatment on the treated
TU	Treatment on the untreated
UBOS	Uganda Bureau of Statistics
UCA	Uganda Census of Agriculture
UGX	Uganda Shillings
UNDP	United Nations Development Programme
UNHS	Uganda National Household Survey
UNPS	Uganda National Panel Surveys
US$	United States Dollar
USAID	United States Agency for International Development
VIF	Variance Inflation Factor
WB	World Bank
ZARDI	Zonal Agricultural Research and Development Institute

GLOSSARY

Agricultural Innovation Systems (AIS): According to Spielman (2005) and Triomphe et al. (2007), AIS is the participatory generation, dissemination, and utilization of agricultural-related knowledge or technology by a spectrum of actors ranging through scientists, farmers, input suppliers, traders, food stockists, extension workers, the private sector and other interested stakeholders. Actors in AIS are motivated by mutual interest to ensure that the chosen commodity generates ample benefit to all in the value chain. The AIS approach therefore assumes the value chain formation in its multi-stakeholder dynamic. In Uganda, farmer participation in AIS initiatives is most importantly through membership of Agricultural Innovation Platforms (AIPs).

Agricultural innovations and/or technologies: The Cornell policy review by Parvan (2010) defines agricultural technology as being a new, scientifically derived, often complex input supplied to farmers by organizations with deep technical expertise. Underwood et al. (2013) explain the term "technology" as being generally used to mean the application of knowledge to produce output through optimum use of combined inputs. In the context of this study, agricultural innovations/technologies include: improved cassava varieties, certified seed of improved cassava varieties, cassava seed delivery systems/channels and Agricultural Innovation Systems approach of technology generation, promotion and utilization.

Cassava Seed Entrepreneurs (CSEs): CSEs refer to farmers who are actively engaged in production of certified cassava seed. Any person who wants to take up certified cassava seed production must register with Department of Crop Inspection and Certification (DCIC) of MAAIF or through any agency accredited by MAAIF. Seed entrepreneurs must register their fields each year and request for inspections every season. Only approved seed fields by DCIC or accredited agency are eligible for issuance of a certificate of field inspection allowing the certification of the field for seed multiplication (MAAIF 2015).

Certified cassava seed: This refers to certified seed, produced under a certification program, that must conform to the appropriate conditions in the certification scheme and the fulfillment of these conditions must be confirmed by the relevant authorities.

Certified seed can be produced on a large scale by certified seed growers or seed companies for general crop production. Certified seed can be produced both in the first and second generations (MAAIF 2015). FAO promotes certified planting material or seed so as to have a realistic quality assurance process and standards for seeds in countries that are at the initial stages of seed industry development. In this regard, fields and planting materials need to be inspected periodically by qualified staff and particularly at the time of harvesting the materials for distribution (FAO, 2007).

Dependency ratio: This refers to an age-population ratio between those typically not in the labour force (the *dependent* part ages being 0 to 14 and 65+) and those typically in the labor force (the *productive* part ages being 15 to 64). The dependency ratio is used to measure the pressure on the productive segment of the population in the sense that a higher ratio would indicate more financial stress between working people and dependents.

Focus Group Discussions (FGDs): This is a qualitative data collection technique used to elicit specific information through a guided conversation between an interviewer and a small number of participants.

FGT Poverty indices: The Foster–Greer–Thorbecke poverty indices were introduced in a 1984 paper by economists James Foster, Joel Greer and Erik Thorbecke. The FGT poverty measures are additively decomposable and they include the Headcount Index (P0), the Poverty Gap Index (P1), and the Severity of Poverty Index (P2). The head count index measures the rate of poverty, which is the proportion of people living below the poverty line. The poverty gap index measures the depth of poverty, which is the extent of income shortfall from the poverty line. The poverty gap-squared index measures the severity of poverty that indicates the degree of income inequality among the poor themselves (Verme, 2006).

Household: In the context of this study, a household (HH) is defined as a group of persons usually, but not exclusively related as kin, who form a more or less independent production and consumption unit during the cropping season (Matlon, 1988).

Household productivity measures: Productivity means output per unit input. This study used two productivity measures: Cassava stem yield (Bags/acre) and Cassava root yield (Kgs/Acre). Note that 1 acre is about 0.405 hectare and one hectare contains about 2.47 acres. In this study, we largely used acres as a land area measurement unit because in the Ugandan context, acres are more commonly and officially used than hectares. This is because of the very small land holdings common amongst the majority of rural small scale Ugandan farmers. To minimize errors in data collection especially where farmers self-report land area data, it is more reliable to capture the data in the land area unit that the farmers are used to which is acres. On another note, for the findings of this study to be relevant to some of the targeted audience i.e. (Ugandan policy makers and rural farmers) land is better appreciated in acres which they are used to than hectares.

Household welfare measures: Household welfare may be defined as a household's command over market and non-market goods and services at the household level (Smale, 2006). In this study, the two major proxies used to measure household welfare are; (a) total household consumption expenditure and (b) total household cassava cash income- both adjusted by Adult Equivalent Units (AEUs) (Asmah, 2011). Using AEUs is important since not all household members would provide farming labour, and if they did, to the same level (Runge-Metzger, 1988). Therefore use of AEUs allows comparison of data for households with different compositions. According to Magrini and Vigani (2016), per capita household total consumption expenditure has been used as a proxy for household income while many other authors have used it as a proxy for food security (e.g. Amare et al. 2012; Asfaw et al. 2012a and b; Kathage et al. 2012; Awotide et al. 2013), on the basis that at lower income the total consumption is limited and so is the expenditure dedicated to food and beverages. This makes it a powerful outcome variable in the context of this study.

Improved varieties: Improved varieties are those that have been genetically boosted through scientific research to attain desirable attributes that may increase their survivability, suitability and productivity.

Livelihoods: According to Chambers (1992), a livelihood comprises people, their perceptions, capabilities and their means of living, including food, income and assets. The term livelihood comprises the capabilities, assets and activities required as a means of living. A livelihood is a means of making a living which encompasses people's capabilities, assets, income and activities required to secure the necessities of life. A livelihood is sustainable when it enables people to cope with and recover from shocks and stresses (such as natural disasters and economic or social upheavals) and enhance their well-being and that of future generations without undermining the natural environment or resource base (Chambers and Conway, 1992).

Non-parametric methods: These are methods whose data is not required to fit a normal distribution, which is often ordinal or ranked.

Parametric methods: These are methods that rely on data that largely follows known distribution patterns usually normal distribution patterns.

Seed: Seed is defined as a generative or vegetative part of a plant that is used as a propagation material (FAO, 2007).

Seed certification: This is a quality assurance system of official control and inspection of seed intended for marketing. The system certifies that a sack, packet or bundle of seed contains what it says on the label and that the seed was produced, inspected and graded, in accordance with the requirements of a Certification Scheme. Certification of cassava seed is accomplished by application for certification by the seed merchant or seed grower (entrepreneur), verification of seed source by the inspection office, field identification and inspection, sampling and analysis for systemic pathogens and grant of certificate and certification tags (MAAIF, 2015).

Seed inspection: This means inspection of the growing plants in the field by a qualified inspector following specific procedures for the purpose of determining the varietal purity of a seed crop, plants affected by pests and diseases, presence of undesirable plants and general condition of the seed crop (MAAIF, 2015). Seed inspection involves any activity conducted by a crop inspector from seed acquisition through site selection, land preparation, planting, agronomic practices during the growth period, harvesting, packaging, labelling, storage and transportation requirements. Field inspection is done by the crop inspector. All cassava seed fields are inspected to confirm the identity of the variety, to ensure that they meet the minimum level of varietal purity and plant health standards. There are mandatory requirements with regard to the minimum isolation distance from cassava crops, and the crop rotation history of the land on which the seeds are grown. The first inspection is done at the site selection stage, second inspection is at 3 months after planting, third inspection at 6 months and fourth inspection at harvest, 9-16 months and is followed by issue of certificate. At harvesting time, the seed entrepreneur is issued with plant movement permit provided by NSCS to confirm that the seed being transported is from the certified field (MAAIF, 2015).

Seed Inspector: This refers to an officer designated/assigned and responsible for conducting the work of inspection, sampling, testing, supervising, guiding and controlling the implementation of seed law (MAAIF, 2015).

Seed quality: This means physical quality as measured by physical purity and freedom from undesirable materials, physiological purity as measured by germination and vigour, genetic purity as measured by varietal purity and health quality as measured by freedom from insects, pests and diseases (MAAIF, 2015).

Seed system: This is defined as a systematic arrangement of procedures, rules and regulations to ensure adequate seed supply to the farming communities. It cuts across the production, processing and distribution of seeds (FAO, 2007).

Variety: This is a population of plants which have common ancestors and which have certain characteristics such as morphological, physiological, cytological and chemical or others of significance for the purpose of agriculture, horticulture or forestry and which when reproduced sexually or asexually retain their distinguishing characters (MAAIF, 2015).

Welfare: This means availability of resources and presence of conditions required for reasonably comfortable, healthy and secure living.

1 CHAPTER ONE: INTRODUCTION

1.1 Background

Most sub-Saharan African (SSA) economies heavily depend on agriculture that is dominated by poor and resource-constrained smallholder farmers living in rural areas. While the agricultural sector employs about 65-70 percent of the total labor force in SSA, it contributes only about 25-30 percent of the total gross domestic product. Women make up over 43 and 50 percent of the global and African agricultural labor force respectively (FAO, 2015a, World Bank, 2016a, 2016b, FAO, 2011). Thus the fate of the agricultural sector directly affects economic development, food security, poverty alleviation, social welfare and gender equality in most of the SSA nations. However, the performance of agriculture in the SSA has not lived up to expectations in as far as it has remained characterized by decades of stagnation and volatility in production and marketed volume. The World Bank Global Monitoring Report (2016) avers that despite some inroads into productivity-enhancing agricultural technology adoption, agricultural success stories in Africa are few compared with the experiences in Asia and Latin America, and that yields per hectare in Africa are about the same as they were in 1970. Despite all this, agriculture still holds the highest potential for enhancing food security and poverty reduction among the rural poor (FAO, 2015a; World Bank 2016a, 2016b).

In Uganda, agriculture accounts for 70 percent of the country's employment (the majority of these being poor smallholder farmers) while generating only 23.6 percent of national Gross Domestic Product (GDP) (MFPED, 2014; UBOS, 2016). Agriculture is the largest single economic sector in Uganda but lags far behind the rest of the economy in terms of productivity. Ugandan agriculture has grown at an annual rate of 2.9 percent in the period since 2000 and at closer to 2.0 percent per year from 2010-2014, lagging well behind overall annual growth in the economy (5.8 percent) and also behind the annual population growth rate (3.3 percent) over the same period (MFPED, 2014; UBOS, 2016). It has also lagged behind the 6 percent per annum growth target for agriculture called for by the Comprehensive Africa Agriculture Development Program (CAADP) and Uganda's own National Development Plan (NDP). This recent slow growth notwithstanding, Uganda is widely considered as one of the countries with the highest agricultural potential in East Africa, and that there is a real opportunity for rapid growth in the sector (World

Bank-ACDP-PAD, 2014; MFPED, 2014). Thus raising agricultural productivity would contribute significantly to poverty reduction and help improve food and nutritional security, as well as to overall economic growth (World Bank, 2016b).

Several biophysical and socioeconomic factors have been identified as key constraints limiting productivity growth in agriculture in sub-Saharan Africa and Uganda in particular. These include: declining soil fertility, lack of high-yielding varieties, scarcity of clean planting material, pests and diseases, and poor marketing infrastructure. Lack of improved quality modern seeds is considered as the main limiting factor for increasing per capita food production for most smallholder farmers in the region (Misiko and Ramisch, 2007, World Bank 2016a, 2016b). These factors conspire to constrain agricultural productivity in general and cassava productivity in particular in terms of cassava stem and root yields.

Development practitioners and scholars alike have for long emphasized the importance of improving agricultural productivity, seed access and commercializing agriculture in reducing hunger and poverty in rural areas (Dowrick and Gemmell, 1991; Bua at al., 1997; Datt and Ravallion, 1998; Gollin *et al*., 2002; Timmer, 2002; Thirtle *et al.,* 2003; World Bank, 2008, 2014, 2016b). The United Nations continues to emphasize the need to improve agricultural productivity and food security in their Sustainable Development Agenda. With this increased attention on agricultural productivity and the metrics in place to monitor progress; national governments have an incentive to take policy actions geared towards increasing productivity. In support of this, the World Bank Global Monitoring Report (2016) presents the Sustainable Development Goal (SDG) Number two as aiming to end hunger, achieve food security and improved nutrition, and promote sustainable agriculture. The associated targets of SDG two encompass not only hunger and nutrition but also efforts to boost agricultural productivity, ensure sustainable practices, remove distortionary trade restrictions in world food markets, and enhance the functioning of food commodity markets with better market information to help reduce volatility (World Bank, 2016a).

Agricultural productivity can be improved by strengthening agricultural research and extension to generate and disseminate improved crop varieties of superior attributes, improving timely access to quality certified seed, value addition and access to credit and markets (ICRISAT, 2006; Buah et al., 2011; NARO, 2014, FAO, 2015a,b). Quality seeds of improved cassava varieties are key and can boost production by over 40% (Bua et al 1997; Maredia et al., 1999; NARO, 2014). This is in agreement with the positive role that quality seeds of improved varieties played in the Asia green revolution as discussed in Evenson and Golin (2009). In the 1980s and 1990s, improved varieties are estimated to have accounted for as much as 50 percent of yield growth in Asian countries (World Bank, 2007). In Sub-Saharan Africa (SSA), quality seed has effectively been made available through interventions that embrace Agricultural Innovation Systems (AIS) concepts - an Integrated Agricultural Research for Development (IAR4D) approach that boosted most SSA agricultural research processes (Sanginga et al., 2009).

In Uganda, cassava is currently the second most important staple food crop after plantains with per capita quantity consumption at 101 kg/person/year; daily caloric intake at 300 Kcal/person/day and 13% share of caloric intake (FAO, 2015b). Cassava's suitability to intercrop with a wide range of crops, vegetative propagation and flexibility to time of harvesting makes it a suitable choice of crop for production by smallholder farmers (Bamidele et al., 2008 and Taiwo et al., 2014). Accordingly, Afolami et al. (2015) concludes that the unique attributes of cassava make it an ideal crop for food production and income generation, particularly among resource-poor farmers in tropical regions of the world. Cassava is sold as stems for seed purposes while its roots can be sold/ consumed fresh or as processed products which include dry chips, flour and value addition products such as cassava bread, short cakes, alcohol, starch, etc.

Cassava remains the third most widely grown crop in Uganda, after maize and beans with average production estimated at 5 million metric tons (MT) annually from 2005 to 2007 (UBOS, 2005) and 2.9 million MT from 2008-2009 (UCA, 2008/9). Grown on an estimated area of 871,000 (Ha), the national yield of cassava is estimated to be 12-15 tones/Ha. It is also reported in UBOS (2007) that cassava was produced on 7.4 million individual plots which translated into 1.07 million hectares. The last Uganda Census of Agriculture UCA (2008/09) estimated the number of plots under cassava to be 3.1 million with 1.9 million (61.2%) under pure stand while the national Mean Plot Size (MPS) was estimated to be 0.28 Ha. Studies by the Uganda Bureau of Statistics (UBOS) also show that the share of marketable cassava grew from 16% in 1995/96 to 23% in 2005/06 (UBOS, 2007). Regional trade in fresh and dried cassava has increased over recent years, mainly supplying South Sudan and the Democratic Republic of Congo (DRC). Studies conducted in 2011 and 2014 (1,068 households sampled from 4 agro-ecological zones of Uganda) indicated that, on average, farmers produced 5,000 kg of fresh cassava /acre (~ 12.5 t/ha) using a mixture of improved (67%) and local varieties (33%) (NARO 2011, 2014).

In consideration of the policy and research support it has received over the past few decades, cassava is being transformed into one of the most important enterprises in Africa. A number of industrial products such as high quality cassava flour and starch are currently produced from cassava. As the uses of cassava go industrial in Africa, the demand for cassava has increased, leading to increased production (FAO/IFAD, 2005). There is now more cassava produced in Africa than the rest of the world combined. Available FAO data shows that from 2000 to 2013, about 60 per cent of the increases in global cassava production were realized in Africa. FAO/IFAD (2005) reported that by 2020 over 60 percent of the global cassava production is expected to be in Africa. At continental level, Yidana et al. (2013) report that consumption-wise, cassava is now the second most important crop after maize, contributing over 40 per cent of the food calories consumed in Africa and supporting over 200 million people on the African continent as a major staple food crop.

Having been prioritized by the New Partnership for African Development (NEPAD) as a “poverty fighter” (NEPAD, 2004), cassava holds the highest potential as a food and income security crop in Sub-Saharan Africa (SSA) largely because of its unique positive attributes of high water stress tolerance levels, long soil storability (such that farmers can harvest it over a long period of time) and high calorific value among others (Jarvis et al., 2012). In Uganda, initiatives to increase cassava production and productivity using AIS[1] concepts and approaches have been implemented with the dual aims of increasing food security and household income. This has remained the hallmark of cassava breeding programs in the National Agricultural Research Organization (NARO) of Uganda resulting in the release and

[1] According to Spielman (2005) and Triomphe et al. (2007), AIS is the participatory generation, dissemination, and utilization of agricultural-related knowledge or technology by a spectrum of actors ranging through scientists, farmers, input suppliers, traders, food stockists, extension workers, the private sector and other interested stakeholders. Actors in AIS are motivated by the mutual interest to ensure that the chosen commodity generates ample benefit to all in the value chain. The AIS approach therefore assumes the value chain formation in its multi-stakeholder dynamic. AIS has many definitions and this is one of them.

dissemination of 19 cassava varieties between 2000 and 2013 (NARO, 2011, 2014). Most of the generated cassava varieties have been adopted in the major cassava growing regions of Uganda to varying levels ranging between 65-77 percent (Wellard et al. 2015). The seemingly high adoption levels have been as a result of intensive government seed multiplication and distribution programs, farmer cassava innovation platforms, NGO seed distribution works, farmer initiatives and other development programs (NARO, 2014; Wellard et al., 2015).

Although efforts have been made through farmer innovation systems to breed better varieties that increase yield and are resistant to emerging diseases, the traditional private seed companies have not pursued them (Otim-Nape and Bua, 1997; NARO, 2014). Vegetatively propagated crops generally have been ignored both due to their complex multiplication and distribution requirements and because of the perceived low value of a seed system where the common practice is to re-use (for instance stems for cassava) (Tadesse et al., 2013). Historically, cassava had been a marginalized crop in Africa in the sense that it had not received as much attention as cereals from various stakeholders including policy and research (Rosenthal and Ort, 2011). This was partly due to its perishability, bulky nature and undeveloped value chains.

Cassava seed sources for production continue to be through four main sources, namely: 1-Farmer source which includes use of home saved seed and seed accessed from fellow farmer (45.7%); 2-Government sources which have phytosanitary seed inspection and certification services embedded. The government sources include the research and extension agencies of National Agricultural Research Organization (NARO) (9%) and National Agricultural Advisory Services (NAADS) (33.2%). The other cassava seed access sources are; 3-Non-Governmental Organizations (NGOs) (10%); and lastly 4- Private MAAIF-certified Cassava Seed Entrepreneurs (CSEs) (1.1%) (NARO, 2014).

Improved cassava varieties developed by NARO are available in Uganda and there is high demand for these cassava planting materials. A multiplicity of institutional and private producers is becoming very active in commercial and sometimes large-scale production of cassava planting material. While the Seed and Plant Act (2006) and Seed and Plant Regulations (2009) provide the legal framework in Uganda for seed multiplication, marketing and quality assurance, there is a conspicuous absence of adequate quality assurance in the cassava seed delivery systems.

Although cassava is an important crop in Uganda, on-farm yields are between 8.0 and 12.0 t/ha (Fermont et al., 2009), compared to 25 t/ha reported on research stations (NARO, 2011). This constitutes a yield gap of up to 13 t/ha. The yield gap is largely occasioned by inefficiencies in access to quality improved seed. The latest Uganda Census of Agriculture of 2008/09 reported that the three major cassava growing regions in Uganda are: the Eastern region leading with 342,387 ha followed by the Northern region with 269,886ha and lastly the mid-Western region at 131,328 ha (Uganda Census of Agriculture, 2008/09; UBOS, 2016). These same regions still possess the highest poverty levels in the country (MFPED, 2014) and are also grappling with agricultural productivity (stem seed and root tuber harvests per unit area) and welfare (low cassava sale cash incomes and low household consumption expenditure) challenges (Kumakech et al., 2013; Pariyo et al., 2015; World Bank, 2016b).

Historically, agricultural research in Africa represents a long search for a research paradigm that has the expected impact upon farmers' livelihoods (Byerlee and Eicher, 1989). Compelled by the realization that the impact of agricultural research was unsatisfactory, agricultural research was pressed for tremendous reforms in Sub-Saharan Africa (SSA) (ASARECA, 1997; Omamo, 2003; FARA, 2005). Further still, the lack of clear articulation of impact from research investments was raised as a concern for governments, donors, and civil society alike and led to reduced budget allocations and to alternative funding mechanisms such as the competitive grant schemes in most African National Agricultural Research Systems (NARS). In response to the concerns, a new way of working was advocated that encourages researchers to design research and innovation processes that go beyond experiments and participation along linear reductionist models that had been promoted for a long time by NARS. Following decades of persistent poverty, low agricultural productivity, food insecurity and human suffering in many of the SSA countries, a re-thinking of the linear top-down national agricultural research approach led to a shift in global agricultural research to systems that enable greater individual and community innovation, proper use of knowledge and overall transformation

(World Bank, 2007a; Martin, 2009; Sanginga et al., 2009, Mapila et al, 2012; Wellard et al., 2013). Scholarly articles in Sanginga et al., (2009) explain that the new prevailing agricultural research paradigm strongly features agricultural innovation in national strategies for many countries working towards long-term agricultural development.

In light of this, agricultural research and development agencies in Uganda have for many years embraced the application of Agricultural Innovation Systems concepts in agricultural research and technology uptake promotion to improve rural livelihoods. This is evidenced from the numerous agricultural Multi-stakeholder Innovation Platforms that are being institutionally supported by NARO where smallholder farmers have embraced AIS approaches by harnessing their local social networks and capital to mobilize for collective action in various endeavors of their agricultural enterprises (Nyikahadzoi, 2012). Participating in Agricultural Innovation Platforms (AIPs) increases opportunities for learning and accessing new technologies leading to better farming outcomes as compared to the traditional extension systems.

However, due to the difficulties associated with measuring the complexities of agricultural innovation interactions and performance in Uganda and SSA in general (Martin, 2009); there has been a lack of empirical evidence that provides conclusive policy recommendations benchmarked on the usefulness of innovation systems in African agriculture (Spielman, 2006). The complexities of impact measurements of AIS interventions result in the use of non-diversified descriptive methods to assess the outcomes of the application of agricultural innovation systems in the developing country context (Spielman, 2006). As a result of this, allocation of resources for promoting the use of innovation concepts in agriculture by policy makers has suffered a great deal further threatening African agricultural recovery (Spielman, 2006; World Bank, 2007b; Spielman & Kelemewonk, 2009).

However, Hall (2007) argues and proposes that the focus of the global agricultural research and development arena and policy makers worldwide should be on innovation and innovation systems as a key to unlocking African agriculture and in creating self-sustaining agricultural systems. AIS being a recent development phenomenon, Riika et al. (2008) suggest further probing of its effectiveness and one way of doing this is through understanding of the impacts of AIS participation on household productivity and welfare in the cassava growing communities where it has been applied for years. Thus, through a robust impact analysis, this study sought to illuminate further the importance of AIS as a research for development approach and has generated evidence-based recommendations for its improvement. Against this backdrop, it becomes necessary to generate robust empirical evidence necessary for innovation systems thinking to become relevant to policymaking and positively contribute to farmer livelihoods and recovery.

Most agricultural technology adoption impact evaluations have concentrated on grains and largely shunned cassava despite its enormous importance both as a food security and industrial commercial crop. One of the reasons for shunning cassava is that the crop has data challenges because of its piece-meal[2] harvesting process while cereal yield data is more accurate, available and reliable. It should be further noted that because of a lack of farm record keeping culture, high illiteracy levels amongst rural farming communities and the above noted piece meal cassava harvesting way of life in most households, there is potential for measurement error in farmer reported cassava root yield data generated through recall. Piece-meal harvesting means harvesting in small amounts required for the day's meal as opposed to harvesting the whole field at once such that it becomes difficult to later recall the total quantities that were harvested from a given area. Mental aggregation of quantities harvested at different times becomes erroneous especially for largely illiterate farmers who don't keep farm records at all. To mitigate this challenge of potential for measurement error in cassava root yield, this study employed the following remedies as mitigation measures: a) repeated recall rigour[3] which means intensive probing by repeatedly asking the farmer in different ways to remember and estimate the root tuber quantities harvested from an acre; b) visualization[4] which refers to the act of mental reflection to form images in the mind, in order to imagine or remember with increased accuracy and c) real time plot[5] root harvest (where possible) which refers to the act of measuring off a small piece of garden and

[2] Piece-meal harvest means harvesting in small amounts required for the day's meal as opposed to harvesting the whole field at once.
[3] Repeated recall rigour refers to intensive probing by repeatedly asking the farmer in different ways to remember and estimate the root tuber quantities harvested from an acre.
[4] Visualization refers to the act of mental reflection to form a picture of something in the mind, in order to imagine or remember with increased accuracy.
[5] Real time plot root harvest refers to the act of measuring off a small piece of garden and physically harvesting it to get the quantity of root tubers which is then extrapolated to the entire garden size.

physically harvesting it to get the quantity of root tubers which is then extrapolated to the entire garden size. It should however be noted that even with these approaches, measurement errors may not be completely eliminated. However, this measurement error applies to the entire sample (adopters and non-adopters) implying that the errors get evened out and therefore does not bias the results of the study.

Having attempted to capture root yield data from the respondent farmers using repeated recall rigour, visualization, and real time plot root harvest farmer reported estimations, this study applied robust impact estimation strategies on the neglected but all-important commodity. With dwindling global resources, support is increasingly being channeled to sectors that empirically demonstrate impact on beneficiaries (WB Report, 2013). With the current emphasis on institutionalization of impact culture amongst development programs (World Bank, 2005; Asfaw, 2010, 2013), the effectiveness of agricultural investments ought to be understood for best policy practice and hence merits investigation.

In the next section, a detailed research problem statement and the corresponding justification are presented, followed with objectives and questions of the study in section 1.3. The research hypotheses and conceptual framework of the study are presented in section 1.4 while survey design, sampling and implementation arrangements are presented in section 1.5. Lastly, section 1.6 presents the outline of the rest of the thesis.

1.2 Problem statement and justification

Adoption studies conducted in the major cassava growing regions of Uganda show high adoption levels for cassava improved varieties at 65-77% (NARO, 2011, 2014; Wellard et al., 2015); but poverty levels have remained high (19.7%) amongst cassava growing communities (MFPED, 2014). Cassava tropical viral disease (CBSD & CMD) prevalence is still a problem in most cassava growing communities despite efforts to encourage farmers to use certified seed. It is noteworthy that the combined effect of CMD and CBSD can lead to 100% crop loss (Otim-Nape et al., 1994; Hillocks et al., 2003; Alicai et al., 2007; Kumakech et al., 2013; Pariyo et al., 2015).

Despite the potential benefits from using certified seed of improved cassava varieties which include safety from disease effects and increased yields, farmers in the cassava growing regions of Eastern, Northern and Western Uganda still experience productivity challenges of seed transmitted crop diseases expressed in sub-optimal stem and root yields (Kumakech et al., 2013 and Pariyo et al., 2015). This study assumes that farmers like any other economically rational individuals are profit maximisers or loss minimisers, who in agreement with the profit maximization theory, would, as a behavioral response, voluntarily choose to use technologies (certified seed of improved cassava varieties) which are observably profitable and resultantly increase their productivity (stem & root yield) and welfare (measurable through crop sale cash income and household consumption expenditure). This is especially true for resource constrained farmers with limited alternatives to improve their production and welfare (Kuntashula and Mungatana, 2013). Further still, technologies that have been generated and promoted through AIS approaches as has been the case in Uganda, ought to be adopted in packages such that use of unclean and potentially diseased seed is a contra-indication amongst cassava growing communities.

The National Agricultural Research Organization (NARO) of Uganda conducted a comprehensive baseline study (a precursor to this research study) that investigated farmers' sources of cassava seed and found out that only 42.2% of the farmers use certified seed accessed from the government agencies NARO and NAADS as well as from certified Cassava Seed Entrepreneurs (CSEs) (NARO, 2014). Despite several campaigns encouraging farmers to use quality seed as a safety mechanism against the cassava viral diseases (CBSD & CMD), Kumakech et al., (2013) and Pariyo et al., (2015) report significant cassava productivity and welfare challenges resulting from use of unclean seed. The productivity challenges relate to low cassava product (stem-seed and root tuber harvests per unit area) while welfare challenges include low cassava sale cash income and household consumption expenditure. This therefore unveils the need to examine: (a) the impact of the AIS approaches used in the cassava technology generation, promotion and utilization; (b) the factors that influence farmers' choice of seed sources; and (c) whether use of improved and certified seed significantly increases farmer productivity and welfare as compared to use of improved uncertified and local traditional seed. There exists only a few and methodologically insufficient studies done so far in Uganda and elsewhere on any of the above questions in relation to the cassava commodity. Where studies have been done elsewhere and on other crops, they are fraught with methodological challenges incapable of yielding robust evidence as elaborated below.

Many studies have identified institutional factors and high transaction costs as major input-output marketing constraints for smallholder farmers in developing countries especially Uganda. Factors such as distance to market, poor infrastructure, lack of input market information, trust, and farmer group dynamics are associated with under-use of different input and output market channels (Jari and Fraser, 2009). Linking technological progress with institutional innovations, Agricultural Innovations Systems (AIS) and markets to engage the diverse set of actors in any particular farming system is at the heart of future productivity growth (World Bank, 2008). Overcoming these constraints requires understanding the performance of the AIS initiatives implemented in the rural cassava farming communities as well as factors influencing farmers' choice of cassava seed marketing channels. Literature appraisal shows a dearth of empirical evidence on the performance and effectiveness of AIS approaches in the cassava technology interventions in Uganda.

Further still, limited empirical inquiry has been done to investigate factors influencing farmers' choice of cassava seed access sources in Uganda. In studying the factors influencing maize grain market channel choice in Tanzania using Multinomial logit model (MNL) model, Mmbando et al. (2014) omit important variables such as the influence of NGOs, influence of media and quality assurance issues in their estimation and yet they strongly explain the dependent variable (choice of market channel). Ndunda and Mungatana (2013) also used MNL regression modeling to study determinants of the farmers' choice of innovative risk reduction interventions to waste water irrigated agriculture in Kenya. Their analysis however excludes important institutional economics variables of trust and household wealth indices which strongly explain the dependent variable (choice of innovative risk reduction interventions).

From a policy perspective, it is imperative that the technology innovation systems (AIS) approach implemented in cassava technology generation, promotion and utilization be appraised to empirically demonstrate its impact (objective 1 of this study). Furthermore, a study (objective 2) that will investigate determinants of farmers' choice of cassava seed access sources by exhaustively looking at all possible factors is important as it will inform practical interventions required to guide cassava farmers' choice of seed access sources and ultimately curb cassava productivity challenges caused by poor seed use leading to increased productivity and welfare improvements.

Given the critical and central role of agriculture in SSA economies, high quality agricultural data and analysis are paramount to informing policy aimed at poverty reduction (FAO/IFAD, 2005). The body of literature on the productivity and welfare impact of agricultural technology adoption is rich but yet inconclusive. A critical review of the current literature on the studies that estimate productivity and welfare impact shows that agricultural technologies and innovations significantly improve household productivity and welfare (Diagne, 2009; Diagne et al., 2009; Asfaw, 2010; Asfaw et al., 2011; Kassie et al., 2011; Kuntashula & Mungatana, 2013); and (Mmbando et al., 2014; Khonje et al., 2015 and Magrini and Vigani, 2016). However, none of the studies cited above has considered the channel by which the technology was disseminated as having a causality effect on the welfare outcome dependent variables. Kuntashula & Mungatana (2013) also did not examine the determinants of adoption of the technology whose impact they attempted to estimate. These partial analyses omit important evidence required to effectively guide policy holistically from the technology adoption-impact viewpoint. Moreover all the above cited studies except Asfaw et al. (2011) and Mmbando et al. (2014) have used only per capita income as a proxy for welfare yet per capita household consumption expenditure is arguably a better welfare proxy or welfare outcome indicator (Asfaw et al., 2011) and Mmbando et al., 2014).This is because per capita consumption expenditure is less prone to measurement error than total household income. Asfaw et al. (2011) and Mmbando et al. (2014) further assert that household income indicates the ability of the household to purchase its basic needs of life while per capita consumption expenditure reflects the effective consumption of households and therefore provides information on the food security status of the household. This inquiry used household consumption expenditure as the main welfare measure and covered the major cassava growing regions of Uganda thereby essentially covering the entire cassava sub-system of Uganda.

Other studies citing positive and significant improvement in welfare among farmers adopting improved agricultural technologies exist (Akinnifesi, et al., 2006; Ajayi, et al., 2007; Franzel, 2004; Place et al., 2002; Quinion, et al., 2010). However, the validity of the welfare estimates from the above cited studies is limited by use of non-robust methods, with most of the studies largely failing to go beyond estimating basic incremental benefits and return to investment in the technology. Furthermore, most of these studies ignore heterogeneity in several farmer and farm observed and unobserved characteristics that exist between those households that did and those that did not adopt improved technologies (Kuntashula and Mungatana, 2014). Self-selection and endogeneity bias usually characterize a non-random treatment assignment in observational data such as the decision to adopt agricultural technologies. Endogenous switching regression modelling when used in a complimentary fashion with Propensity Score Matching (PSM) is able to control for the unobserved heterogeneity not addressed by the matching techniques. However, the studies reviewed fail to isolate the causal effect of improved technology adoption on crop productivity and household welfare.

In summary, it is clear that a research problem exists backed by a research gap manifested in the inadequacies identified in the multitude of previous studies done on impact estimation of agricultural technology adoption. These inadequacies include, inter alia: (a) assessing the effects of single technologies (usually only seed genetic improvement), disregarding the impact of other important complementary innovations such as seed certification; (b) evaluating the impact of agricultural technologies using sub-national location specific datasets at district or regional levels thereby disregarding nationally representative datasets; (c) limiting the analysis to a single measure of productivity (usually grain yield) or welfare (incomes or consumption expenditure) disregarding the fact that both productivity and welfare are multi-dimensional and complex phenomena which cannot be understood through single indicators; (d) estimating impact of technology adoption using less rigorous estimation methodologies that lack frontier robustness checks; (e) shunning root crops especially cassava whose piece meal harvesting regimes occasion enormous yield data challenges and instead conveniently over-studying grain crops whose data challenges are limited.

Thus, in addition to examining the performance of the AIS approaches used in cassava technology generation, promotion and utilization and determining what causes farmers to source seed from certain seed sources and not others; this study explicitly takes into consideration the possibility of self-selection and endogeneity bias in cassava technology adoption as well as triangulating impact results estimated from the most reliable methodological approaches. On this partial account, this study submits that it makes an original contribution to the existing body of organized knowledge in the topic under investigation. Further still, a comprehensive attempt at addressing the inadequacies (a) to (e) cited in previous studies as elaborated above is considered by this study as a significant contribution to knowledge. Given that Uganda is currently one of the poorest countries on earth (World Bank, 2015), new empirical links between agricultural technologies, technology delivery systems and household productivity and welfare are crucial to making agricultural policy interventions more effective in improving food security, welfare and living standards of the rural poor. The next section presents the objectives and research questions of the study.

1.3 Objectives and research questions of the study

The overall objective of this study is to generate robust empirical evidence on: the impact of cassava AIS approaches and initiatives in improving the livelihoods of rural smallholder cassava growers, determinants of choice of cassava seed sources; and the productivity and welfare impacts of cassava technology adoption in the context of rural smallholder cassava farming communities of Uganda.

The *specific objectives* are to:

1. examine the impact of cassava Agricultural Innovation Systems (AIS) interventions on the productivity and welfare of cassava farmers
2. examine the determinants of the cassava seed source choices
3. evaluate the impact of cassava technology adoption on cassava productivity and household welfare

The *research questions* are:

1. What are the determinants of participation in Agricultural Innovation System platforms?
2. What is the impact of the cassava AIS interventions on the productivity and welfare of cassava farmers?
3. What are the causal factors influencing the choice of the cassava seed access sources?
4. What are the determinants of cassava technology adoption?
5. What is the impact of improved-uncertified cassava seed adoption on household productivity and welfare?
6. What is the impact of improved-certified cassava seed adoption on household productivity and welfare?
7. Do different impact estimation strategies yield the same impact estimates?

To answer the above research questions and achieve the set objectives, this study used both quantitative and qualitative cross-sectional data that was gathered through a household survey covering the entire cassava sub-system (Eastern, Northern and Western regions) of Uganda. The study used estimation strategies of varying rigor and robustness to test the following hypothesis.

1.4 Hypotheses for the study

Objective one is covered by hypothesis (i) while objective two is covered by hypothesis (ii). Objective three is covered by both hypothesis (iii) and (iv).

Hypothesis (i)

Livelihood outcomes (cassava productivity and household welfare) of cassava farming households participating in AIS initiatives are higher compared to non-participating households

Hypothesis (ii)

Transaction costs and institutional factors influence farmers' choice of the cassava seed source. Transaction cost measures may include access to tarmac roads and transportation means while institutional factors may include farmer group membership, membership to AIPs, farmer networks, and access to extension and credit services. The study attempted to test the hypothesis using each of these measures.

Hypothesis (iii)

The productivity and welfare outcomes of farmers using improved-certified cassava seed is higher than that of the farmers using improved-uncertified or local cassava seed

Hypothesis (iv)

There is equality of productivity and welfare estimates from the different impact estimation approaches used.

The four hypotheses above constitute the structural framework required for analysing the causal effect of cassava technology adoption on cassava productivity[6] (measured by cassava stem and root yield) and household welfare (measured by cassava cash income[7] and consumption expenditure). Thus, their function was also not only to provide a structured framework in the empirical analysis that follows, but also to disentangle the diverse mechanisms of action through which cassava technology adoption and adoption intensity may affect each productivity and welfare measure singly. Next is a graphical presentation of the conceptual framework of the study.

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[6] Stems and roots are two separate products that serve different functions along the cassava value chain. While stems are used solely as seed, roots can be consumed fresh or processed into various food and industrial products. Therefore, stems are not a byproduct of roots but rather an independent product and in most cases are harvested twice before roots are harvested. Also, the unit of measurement of stems is different from that of roots. Harmonization of units of measurement of stems and roots is impractical because while stems are measured in bags, roots are measured in Kilograms such that generating an applicable conversion unit is unfeasible. This is because the productive potential of a stem as seed is determined by the presence of nodes on the stem, which later germinate when planted, and not the weight of the stem.

[7] Cassava cash income was computed using stem sales, fresh root sales and processed root product sales. With regard to individual contribution of stems and roots to cassava income, it is expected that root income is significantly higher than that from stems because while stems are only used for only one purpose (seed) and do not require any form of processing or value addition other than packaging; roots can be sold as fresh roots, and can also be processed through value addition into several products (i.e. flour, chips, food products) such that their value increases with the level of value addition.

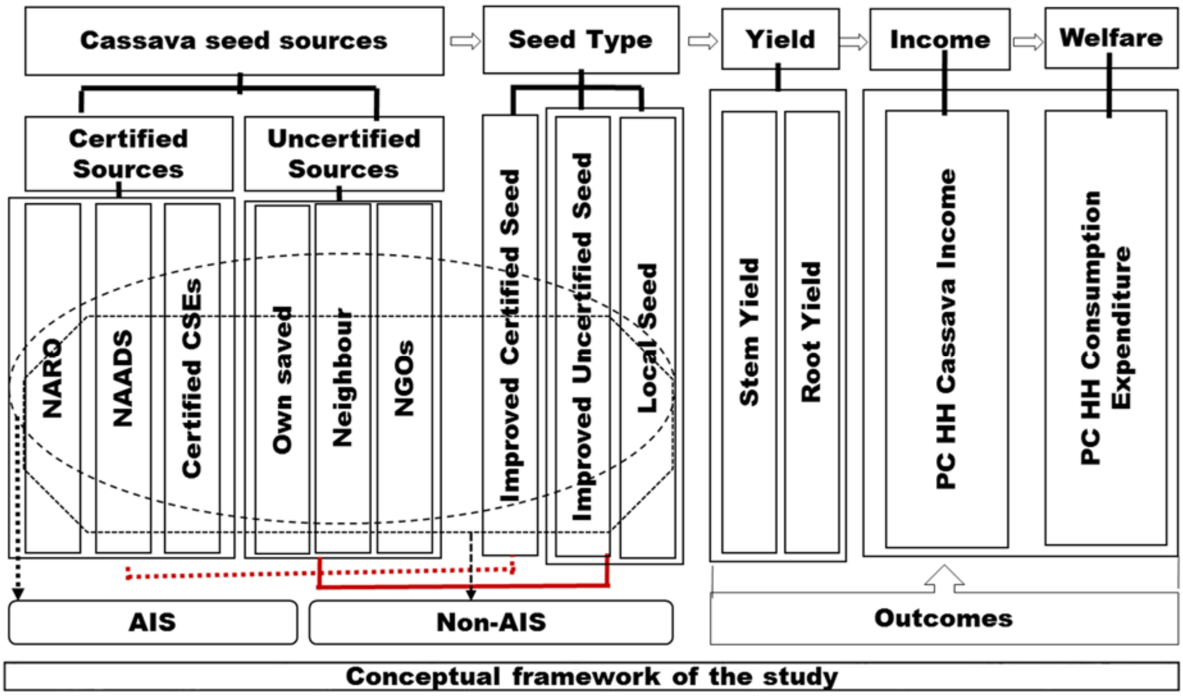

Figure 1.1: Conceptual framework of the study

Key to Fig 1.1	Explanation of the conceptual framework of the study
………….. AIS & Non-AIS	Farmers may participate (dotted oval) or not participate (dotted octagon) in AIS initiatives through membership or non-membership of AIPs respectively. *It is hypothesized (Hypothesis 1) that livelihood outcomes (cassava productivity and household welfare) of cassava farming households participating in AIS initiatives are higher compared to non-participating households*
Cassava seed sources and seed type	Cassava seed can be accessed through certified (dotted orange line) or uncertified (continuous orange line) sources. From certified sources we get improved certified seed while uncertified sources give improved uncertified or local seed. *It is hypothesized (Hypothesis 2) that transaction costs and institutional factors influence farmers' choice of the cassava seed source.*
Yield, Income and Welfare	Cassava can be sold as stem seed, root tubers, or its differentiated secondary products leading to cassava cash income. A household's consumption expenditure is captured in this study as an additional welfare measure. Stem and root yield are productivity outcome measures while Cassava cash income and consumption expenditure are household welfare outcome measures. *It is hypothesized (hypothesis 3) that the productivity and welfare outcomes of farmers using improved-certified cassava seed is higher than that of the farmers using improved-uncertified or local cassava seed.*

1.5 Survey design and implementation

1.5.1 Study area and sampling procedure

To gather the required cross-sectional data, the household survey covered randomly selected cassava farming households from twelve purposively sampled districts from Eastern, Northern and Mid-Western Uganda. The chosen three regions are the major cassava growing regions of Uganda thereby giving the study a full coverage of the entire cassava sub-system of Uganda. Districts were purposively selected on account of their vibrancy[8] in cassava production for both food security and commercial purposes. To categorize districts into most and least vibrant, this study relied on the findings of the baseline study (NARO, 2014) for the project sponsoring this PhD programme (Cassava Seed System project) with regard to district cassava production levels, crop importance rankings, local significance of the cassava commodity and community participation intensity in cassava initiatives. Findings from Key Informant Interviews (KIIs) of District Agricultural Officers (DAOs) also informed the classification of the most and least vibrant districts. In each region, two most vibrant and two least vibrant districts were purposively selected to act as intervention and control districts respectively. It is important to observe that in both district categories, adopters and non-adopters would be found although much more adopters were found in vibrant districts and vice versa.

The Eastern region districts selected for the survey were Serere and Ngora (vibrant) and Kaliro and Kamuli (less-vibrant). Northern region districts were Apac, and Amoratar (vibrant) and Lira and Oyam (less vibrant). Mid-Western region districts were Masindi and Kiryandongo (Vibrant) and Kyenjonjo and Hoima (less vibrant).

Table 1.1: Districts by region selected for the study

REGION	MOST VIBRANT	LEAST VIBRANT
Eastern	Serere and Ngora	Kaliro and Kamuli
Northern	Apac and Amoratar	Lira and Oyam
Mid-Western	Masindi and Kiryandongo	Kyenjonjo and Hoima

Source: Own primary data

[8] Vibrancy was categorized based on district cassava production levels, crop importance rankings, local significance of the cassava commodity and community participation intensity in cassava initiatives

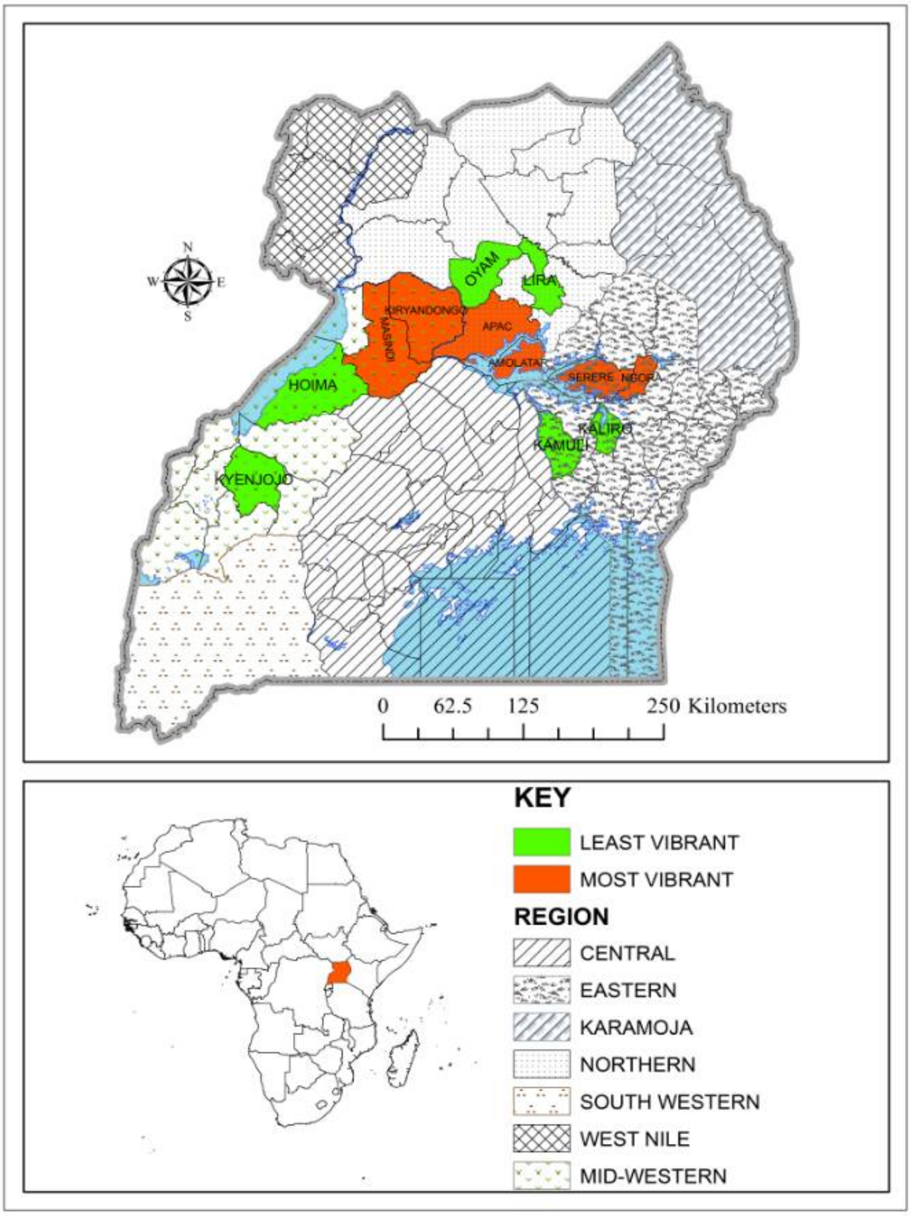

Figure 1.2: Map of Uganda showing study area by districts and regions

The National Crops Resources Research Institute (NaCRRI) databases consisting of coded household cassava growing respondents covered in several previous surveys (carried out over time for different purposes) (NARO, 2011, 2014) provided the sampling frames for this study. This was complimented by an exploratory study (undertaken prior to implementing the main survey) within the identified intervention and control districts of Uganda. Working with the District Agricultural Officers (DAOs), the NARO Zonal Agricultural Research & Development (ZARDI) officers and local agricultural extension officers, lists of registered and active cassava farmers in both the intervention and control districts were drawn alongside the sampling frames from the NARO previous surveys. The scoping exercise helped to illuminate further the distribution patterns of adopters and non-adopters in the sampled communities. This study defined an adopter of cassava innovations as one who used the innovation or technology in the preceding year 2015. For the case of Agricultural Innovation Systems, participation was by membership to any Agricultural Innovation Platform (AIP) in the year 2015 and before.

From each region, two intervention (vibrant) and two control (less vibrant) districts were selected. From each district, 4 sub-counties in which cassava production is intensive were selected. From these 4 sub-counties in every district, 150 active cassava farmers were listed. The reasons for listing only 150 cassava farmers included; (a) road accessibility (with care taken to ensure households distributed across the villages were interviewed and not just those close to the motorable roads - enumerators would be supervised to walk the footpaths and reach remote households), (b) farmer group registration and (c) active cassava production. Considering that the study was covering four districts in each of the 3 regions (Mid-Western, Northern and Eastern); the total population (N) under consideration became:

N= 150*4*3= 1,800 Cassava Farmers

Following Yamane Taro's formulae for calculating sample size (Yamane, 1967);

$$n = \frac{N}{1 + Ne^2} * \frac{100}{r}$$

Where: n = sample size; N = population size; e = acceptable sampling error (taken at 3.5% due to resource envelope limitation); and r = response rate at 95%

$$n = \frac{1{,}800}{\left(1 + 1{,}800 * \left(\frac{3.5}{100}\right)^2\right)} * \frac{100}{95}$$

n=591

To cater for attrition challenges, the study aimed at interviewing an extra 3 households per district leading to a total of 624 cassava growing households in both intervention and control districts combined.

From each of the selected districts, the study aimed at interviewing a minimum of 52 respondents totaling to 208 respondents per region and 624 for the entire sample following the sample size calculation elaborated above. During data processing, 15 questionnaires were discarded for lack of consistency leaving only 609 household questionnaires. Data was collected at both household and parcel levels as necessary. Also, using carefully designed interview guides, one sub-sample Focused Group Discussion (FGD) was held in each district totaling to 12 FGDs for the entire sample. Key Informant Interviews (KIIs) were also held with chairpersons of farmer groups in each district, the District Agricultural Officer in each district and the Zonal Agricultural Research and Development Institute (NARO-ZARDI) official in each region. Throughout the interviewing process, detailed interviewer observations were recorded for cassava garden area and yield estimations, variety identification and homestead parameters. FGDs, KIIs and enumerator observations were purposed to provide the necessary contextual information required to strengthen discussions and arguments from quantitative findings.

1.5.2 Sample size minimum detectable effect size and power of test

In computing the sample size using power calculation under this subsection 1.5.2 (see Appendix A1.1 for stata computation results output), this study utilized statistics from the cassava baseline and end line surveys of 2011 and 2015 on the adoption rates that showed a change from 65% in 2011 to 77% in 2015 respectively (NARO, 2011; Wellard et al., 2015). This is approximately about 12% change which I utilize as a proxy measure for effect size at 80% power. The study assumed that with the Cassava seed system (CSS) project intervention that promoted the various innovations under consideration in this study for about the same number of years as the Eastern Africa Agricultural Productivity Project (EAAPP) which was similar to the CSS project in many aspects, the effect size would remain relatively the same. Accordingly, this study took the lower bound at 11% change for effect size at 80% power (See Stata results output in Appendix A1.1).

This study utilized Stata13 to compute the desired sample size for both the intervention and control areas combined since both adopters and non-adopters could be found in both areas albeit in different proportions as earlier elaborated (see section 1.5.1). As earlier stated in section 1.5.1, the study sampled 4 sub-counties from each of the 12 districts leading to a total of 48 sub-counties herein called clusters. The sub-counties (clusters) are 24 for the intervention (most vibrant) districts and 24 (for the control (least vibrant) districts at a balanced 50% ratio. The stata command is given as: **clustersampsi, binomial detectable difference p1(.5) k(48) rho(.07) m(13)**; where:

p1= 0.5: Ratio of intervention and control clusters which is 50% because they were equal in number

k=48: Total number of clusters within both intervention and control districts. As earlier stated in section 1.5.1, the study sampled 4 sub-counties from each of the 12 districts leading to a total of 48 sub-counties herein called clusters.

rho = 0.07: We assume a weak inter-cluster correlation of 7% so that we attain sufficient variability amongst the sampled respondents

m =13: Number of respondents selected per cluster. The number of farmers selected from each cluster was varied using the stata command to ensure that the desired effect size is achieved at the 80% power. Thus to achieve 80% power, the number of respondents selected per cluster was varied in the stata command formula until it balanced at 13 (see appendix A1.1). The number 13 (respondents selected per cluster/subcounty) is statistically reliable because it is supposed to be low as a way of minimizing chances of finding related households across intervention and control groups. This is also aimed at increasing variability.

Following this approach, the sample size is calculated as the product of the number of clusters and the selected number of households per cluster i.e. n = 48*13=624. Thus the result is that the study aimed at a total sample of 624 households from both the intervention and control groups. This implies that from each of the sampled sub-counties (cluster), the study selected 13 households and atleast 52 households from each district as was earlier derived using the Yamane Taro's formula in section 1.5.1. The results further show that the design effect of our sample size is 1.84 which is close to 1 implying the study is close enough to using a simple random sampling. By definition, the design effect is the ratio of the chosen design (multi-stage cluster sampling) to simple random sampling design which should ideally be 1. During data processing, 15 collected observations were dropped for lack of consistency leaving the study with 609 consistent observations.

1.5.3 Survey tools development

Informal interviews were held with several contact cassava farmers who had repeatedly been interviewed in previous cassava surveys. The informal interviews covered most of the proposed datasets that had been planned to be collected. Using findings from these discussions and a review of literature, a structured household survey questionnaire was developed. The household survey questionnaire (See Appendix A5.5) was then standardized following the World Bank, IFAD, FAO and IFPRI joint Living Standards Measurement Surveys- Integrated Surveys in Agriculture (LSMS-ISA[9]) standard tools making the findings of this study comparable to national and regional contextual statistics. Allowing broader comparability of study

[9] **The LSMS-ISA** is a household survey program focused on generating high-quality data, improving survey methods, and building capacity in SSA. It facilitates the use of household survey data for evidence-based policymaking. Working with Uganda Bureau of Statistics, the project supports the Uganda National Panel Survey (UNPS), and ensures comparability with other surveys being carried out under the LSMS-ISA project in Sub-Saharan Africa.

findings increased validity and reliability of research findings and policy recommendations.

To mitigate (make less severe) the challenges of reverse causality[10] in impact estimation, the questionnaire was designed in such a way that it captured both adoption and pre-adoption data on selected variables such as wealth and assets, access to extension and credit, group membership, etcetera. This is important for assessing impact of technology adoption using pre-adoption covariates. Finally, a qualitative module was developed and added to the household survey instrument and was applied to sub-samples in both the adopting and non-adopting households. The qualitative module involved observational checklists, Focused Group Discussions (FGD) guides and Key Informant Interview guides.

1.5.4 Enumerator training and survey tools pre-testing

The study conducted a 3 day intensive training of the survey team (enumerators, supervisors and drivers) in all the details of the survey to be implemented. The enumerators and supervisors (identified based on their experience, level of training and local language dexterity) were trained about the background of the research, objectives and data requirements. A systematic training in the entire pre-coded survey instrument was done followed with local language question translation and examined role playing. Qualifying assessments were done for each enumerator following which a formal contract was signed between each successful enumerator and the National Crops Resources Research Institute (NaCRRI).

Following the intensive training, role playing, examination and contract signing, a pre-test survey covering 10 improved-cassava-variety adopting and 10 non-adopting households was carried out in Nakasongola district which borders the selected study area and is similar in most geographical and socio-economic characteristics. The pre-test was purposed to (a) ensure that the questionnaire comprised of logically flowing questions well understood by the respondent farmers; (b) provide a second and real practical training opportunity to the enumerators on the

[10] **Reverse causality** means that X and Y are associated, but not in the way you would expect. Instead of X causing a change in Y, it is instead the other way around: Y is causing changes in X**.** In this study context, one would ask: is it asset ownership or access to extension that is causing technology adoption or it is technology adoption that caused asset accumulation and improved access to extension services.

survey implementation mechanics. Basing on the findings from the pre-testing exercise, the survey tools were, in another full day workshop, adjusted and refined to their final versions ready for the actual survey implementation.

During the data collection exercise, enumerators were facilitated to carry, inter alia, packed meals, drinking water, medicines and toiletries, rainproof wear, cameras, printed cassava-variety identifier colored images, first aid kits and standard booklets for conversion of non-standard production units to standard units.

1.5.5 Survey implementation and data collection

This study was based on a cross-sectional household survey data collected from 624 cassava farming households of Eastern, Northern and Mid-Western Uganda. The data was collected using a pre-tested structured questionnaire administered by trained and experienced enumerators who had good knowledge of the cassava seed and general farming systems, and could speak the local languages in the respective selected study areas.

The survey enumerators were trained and supervised by the author in collaboration with the supervisory team at the Natural Resources Institute of the University of Greenwich, University of Pretoria, UN FAO Rome and NARO Uganda. All ethical considerations of the University of Greenwich were adhered to in the conduct of this study. From the randomly selected cassava farmers, data was collected on a set of variables described in different sub-sections of the study.

Under the overall guidance of the PhD programme supervisors and the PhD candidate, the actual data collection lasted 57 days. The PhD candidate was involved in data enumeration, FGD and KII discussions as well as daily cross-checking of filled-in questionnaires. The PhD student was the quality controller of the data collection exercise. Throughout the exercise, measurement error minimization was attained following precautionary guidance notes that were later tabulated by Gourlay et al. (2017).

Table 1.2: Potential sources of error in farmer-reported estimates

Type	Precautionary guidance notes
Measurement Complications	Conversion of non-standard production units to standard units or monetary values
	Variation in crop condition and state at harvest
Unintentional Bias	Recall bias
	Rounding of production quantity
	Partial early/green harvest
	Extended harvest/permanent crops
Intentional Bias	Perceived benefits of under-reporting (such as eligibility for program or service)
	Desire to appear successful, leading to over-reporting

Source: Gourlay et al, 2017

Collected data was cleaned and entered in Epidata data capture software. Following exportation of the cleaned data to STATA version 13, comprehensive data cleaning and exploratory checks were carried out before detailed analysis commenced.

1.6 Outline of the thesis

This thesis is organized under 6 chapters including this introductory chapter. Chapter 2 presents the literature review of the study. Beyond comprehensively defining the key concepts and terminologies used in this study, it provides an overview of AIS as a research for development approach as well as an elaborate illumination of the determinants of cassava seed access channel choices. The same chapter appraises theoretical and empirical evidence on the productivity and welfare impact of agricultural technology adoption.

Chapters 3, 4 and 5 present the conceptual frameworks, methodological approaches, results, discussions, conclusions, policy recommendations, study limitations and further research suggestions for objective 1,2 and 3 respectively. Chapter 6 presents the general thesis conclusions, policy recommendations and suggestions for further research. Next is chapter two on literature review.

2. CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This chapter is an attempt at identifying and appraising appropriate study methods and crystallizing the research gap. Understanding the previous works done helps to locate the study in the wider evolving knowledge-system on impact evaluation and makes a case for the knowledge gap that this research fills. In this regard, reviews of theoretical and empirical literature relating to causal determinants of participation in AIS initiatives and the impact of AIS interventions in the livelihood improvement of farmers is presented. Understanding causal determinants of AIS participation and the resulting productivity and welfare impacts is essential in as far as providing a broader contextual understanding of determinants of seed access sources; determinants of adoption and adoption intensity of agricultural innovations; and adoption impacts of agricultural technologies are concerned. Also, theoretical and empirical considerations of causal determinants of seed source choice and impacts of agricultural technology adoption on household productivity and welfare are presented.

2.2 AIS interventions in livelihoods improvement of rural farmers

2.2.1 Contextual perspectives of AIS

In the broader scope of this thesis, it is postulated that understanding determinants of seed access source choice and impact of cassava technology adoption on household productivity and welfare requires Agricultural Innovation Systems (AIS) thinking which has become an increasingly applied framework to analyze technological, economic and institutional change in agriculture. Therefore, understanding the impacts of the use of innovation systems in different contexts on the continent is more than ever crucial so as to enable the creation of context-specific evidence on which to base policy making. This study is a step towards this realization as further elaborated in the next paragraphs.

Among the cassava farming communities in the studied areas of Uganda, differentiated technology generation, promotion and uptake approaches have been at play for many years. While this has been the case, there is limited evidence of their characterization and impact at household level. In a study that seeks to understand whether the technologies promoted have had an impact on the productivity and welfare of adopting households, it is important, as a foundational step, to attempt to understand the technology generation, promotion and uptake approaches and whether these approaches have had an influence on the adoption patterns, productivity and welfare outcomes of the intended beneficiaries.

This study sought to characterize the different cassava technology generation, promotion and utilization approaches and attempted to assess their impact on smallholder livelihoods following the works of Martin (2009); Scoons and Thompson (2009), Mapila et al. (2012), Wellard et al. (2013), Sseguya et al. (2013), and Mwaura (2014). Results of this inquiry generate capabilities to advise state and non-state actors on policy options and incentive structures that enable greater levels of sustainable innovation and improve the understanding and distribution of outcomes, gains and impacts.

2.2.2 AIS as a research for development paradigm

The Uganda Ministry of Agriculture, Animal Industry and Fisheries (MAAIF, 2010) gives a chronology of agricultural technology generation and promotion systems that have happened in Uganda since the 18th century as follows: extension by compulsion to promote production of cash crops (1898-1956); extension through progressive farmers, who were identified and trained to act as change agents in their localities (1956-1963); extension by education, using government schemes such as demonstrations, farmer field days and trials (1964-1971); the project approach, intended to rehabilitate and restore basic services under the Agriculture Development Project (ADP) (1971-1991); the unified extension approach in which a single extension worker was responsible for transfer of innovations to groups of farmers in a given geographical area (1992-1998); and the National Agriculture Advisory Services (NAADS) approach introduced in 2000 to redress shortcomings of the past extension attempts as well as incorporate international best practices to make extension delivery more efficient.

Despite the evolutionary improvements cited above, it remained a confirmed fact that volumes of agricultural research outputs were piled up unused and that many that had been arbitrarily transferred to farmers had often been mis-adopted with minimal impact (FARA, 2012; Riikka et.al. 2008). This is further compounded by

Kimaro et.al. (2010) who posit that due to lack of participation of targeted beneficiaries in technology generation, promotion and use, a large gap exists between research and adoption of technologies. To circumvent this, Agricultural Innovation Systems approach (AIS) is presented as a new paradigm system that brings together researchers, farmers, extensionists, market agents, and other interested stakeholders in the generation, promotion and utilization of technologies and innovations. The Uganda Agriculture Ministry's Development Strategy and Investment Plan (DSIP) emphasizes the need to improve technology transfer and dissemination (MAAIF, 2010). Since the 2000s, Agricultural Innovation Systems (AIS) thinking became an increasingly applied framework to analyze technological, economical and institutional change in Ugandan agriculture. Through farmer led innovation extension systems, the NAADS II programme (re-designed to include AIS concepts) empowered farmer groups and institutions to demand agricultural advisory services and to participate in input and output markets. Under NAADS II, a new paradigm shift that embraces AIS criteria includes: inclusion of cooperatives and NGOs to provide advisory services with support supervision from public extension services; supporting formation of high level farmer organisations that help farmer groups to enhance their capacity to make and implement decisions and to have vertical and horizontal linkages along the value chain; enhancing farmer marketing and bargaining power; improving access to new technologies and information through formation of stronger research-extension linkages (farmer groups directly work with zonal agricultural research and development institutions of the National Agricultural Research Organisation); linking willing and creditworthy farmers to credit institutions; involvement of the private sector to play a leading role in supporting farmers to strengthen agribusiness and value addition (AfranaaKwapong and Nkonya, 2015).

According to the World Bank (World Bank, 2007a), an innovation system is a network of actors and organisations linked by a common theme with the aim of developing new technologies, methods and forms of organisation for end users to tackle identified problems. It is further elaborated that such a system is governed by the prevailing institutions and policies that affect the performance of the actors involved and the regulation of the technologies developed. While noting that an agricultural innovation system is a research tool for solving agricultural problems, Mapila et al. (2012) explain that the AIS concept embraces not only the researchers and scientists who are traditionally involved in agricultural research but also the end users of the technologies and the interactions that take place between all the actors in the research process.

According to Bruin and Meerman (2001), AIS takes special cognizance of the fact that agricultural problems are site specific and may therefore require input from the local knowledge to develop technical solutions. AIS explores the "let's do it together", and in some cases, a bottom up approach and is not limited to extension. It's an empowering approach which embraces extension as part and parcel of scientific, social economic variables that need to be brought into play to harness agricultural production (Juma, 2011).

In an Agricultural Innovation System, actors such as interdisciplinary teams of scientists, end users, extension agents and agribusinesses interact to identify problems for which innovative solutions are needed. Such a team is known as an Agricultural Innovation Platform (AIP) (Mapila et al., 2012).

2.2.3 Theoretical and empirical considerations of AIS interventions

2.2.3.1 Impact of participation in AIS initiatives

Review of literature reveals that only a few empirical studies have been conducted in Africa to examine the impact of Agricultural Innovation Systems on household productivity and welfare. Using mainly qualitative tools, Morris et al. (2007) studied the role of AIS in food security and nutrition while Gildemacher et al. (2009) examined the role of AIS in increasing food production by using natural resources more effectively. In agreement with Spielman et al. (2009), the studies cited above did not make use of rigorous analytical tools required to distil the impact of AIS on farming livelihoods. Their approaches yield biased results due to selection and endogeneity concerns.

While Mapila et al. (2012) applied a more rigorous empirical analysis approach (Propensity Score Matching) in evaluating the impact of agricultural innovation system interventions on rural livelihoods in Malawi, their study used household income as a major outcome variable instead of consumption expenditure[11] which is by far a better outcome variable in as far as its less prone to errors and represents the true household welfare. Further still, to the extent that the PSM methodology only controls for selection bias due to observable covariates, the impact estimates by Mapila et al. (2012) still suffer endogeneity concerns due to unobservable covariates. This study has successfully used Endogenous Switching Regression Modelling to control for bias due to both observable and unobservable[12] covariates.

Through multiple regression modeling techniques, Kaaria et al. (2008) assessed the performance of the Enabling Rural Innovation (ERI) initiative in linking smallholder farmers to markets and for improving livelihood outcomes in Uganda and Malawi. While the study findings indicated that greater linkages of farmers to markets improved livelihoods through increased accumulation of household assets and investments in farm enterprises, the results' efficacy in advising policy remains inadequate in as far as the analysis did not control for attribution and selection bias problems.

Using gross margin analysis, Magreta et al. (2010) demonstrated how linking farmers to markets using AIS concepts in agricultural research led to improvements in farmers' livelihoods through increased gross margins in the rice-based farming systems of Southern Malawi. To the extent that the study by Magreta et al. (2010) did not measure farmer welfare using household consumption expenditure which robustly explains welfare, the study's policy relevancy is limited. This limitation is overcome by our comprehensive approach that uses household consumption expenditure as the main welfare measure to generate overarching policy implications and recommendations.

In a study by Mwaura (2014), an inquiry as to whether the use of farmer' groups approach in agricultural information dissemination resulted in increased adoption of technologies and improved yields was done using translog production function, and propensity score matching. Still, it can be argued that the results found

[11] Since cassava is more of a food security crop in the context of Uganda, its sales income may only proxy welfare to an extent. To further measure household welfare more robustly, this study, in addition to per capita household cassava cash income, uses per capita household consumption expenditure which includes, inter alia, imputed value of cassava consumed at home.

[12] Whole observable covariates include, inter alia, farm size, family size, education level, wealth status; unobservable covariates include, inter alia, risk taking behavior, farmer personal motivation and farm management skills.

could have been more reliable had the researchers applied robust identification methodologies that control for attribution and selection biases.

In summation, the literature reviewed agrees with Martin's (2009) observation that outcome and impact evaluation of AIS interventions remains rather complex. The literature appraisal confirmed a dearth of empirical inquiry that has applied rigorous quantitative tools to study the impact of agricultural innovation systems interventions on the productivity and welfare outcomes of farming communities. This study attempts to close the knowledge gap identified in this review.

2.3 Determinants of seed source choice in developing countries

Literature review reveals that there exists a dearth of information on determinants of input market channel choice for smallholder farmers. Instead, literature on determinants of output or produce market channel choices is abundant. And yet the agricultural input sector has a critical impact on the agricultural productivity of a nation as it influences farmers' access to and use of productivity enhancing inputs (FAO, 2005a, b). Increased use of improved seeds was partially credited with the large increases in agricultural productivity growth in Asia during the Green Revolution (Evenson and Golin, 2009). It is evident that agricultural input use must increase in Africa if the continent is to see significant productivity growth. Increasingly, consensus has emerged for the need to foster private sector led development of agricultural input markets (Freeman and Kaguongo 2003).

Chigwere, (2014) studied the factors determining farmer's choice of cotton marketing channels in Salima district, central Malawi using Multi-nomial Logit Modeling (MNL) and found that marital status, education of household head, distance to the market, selling price, and membership to associations significantly affected farmer's choice of the market channels. The choice of the MNL methodology was because of the availability of more than two channels. This study faced a binary limited dependent choice variable and therefore opted to use the probit model.

Zivenge and Karavina, (2012) carried out a study in Chinamhora District in Zimbabwe to assess determinants of tomato market channel choices using the logistic model. The logit regression analysis showed that price and cell phone ownership were the major determinants of market choice among farmers. This study recommends that farmers should develop effective mechanisms for collaboration and linkages, invest in market intelligence, and create a sea change in thinking and practice, and building trust. The study further recommends that farmers should join cooperatives to enhance their chances of accessing critical production inputs and that government should provide extension services to improve vegetable production. The study revealed that informal markets are more accessible than formal markets and offer great prospects for the development of communal farmers. The findings of this study provide insights that guide selection of the determinant variables in the probit model used for this inquiry.

Ohen et al. (2013) analysed market participation by smallholder rice farmers in Cross River State of Southern Nigeria using probit model and found that lack of full participation in markets prevents them from transiting into commercial farming and hence their low contribution to economic growth. He discovered that the farmers' market channel choices are influenced by institutional, technical and socio-economic factors that include lack of information, poor infrastructure, inability to have contractual agreements, lack of transport, poor organizational support, low access to extension agents and low use of improved seed. Based on these findings, it is theorized that marketing channel choices among smallholder farmers are influenced by institutional, technical and socio-economic factors.

In many African countries, Uganda included, private investment in input distribution is discouraged by an unfavorable business climate characterized by continued government and NGO procurement and distribution of inputs, which undercut private markets, increases the uncertainty of input marketing, and results in high levels of rent seeking (Morris et al., 2007). Macroeconomic instability, inadequate regulatory systems, and an abundance of taxes and fees also limit the active involvement of the private sector (Morris et al. 2007). With few exceptions, the agricultural input sectors in African countries are small and limited in geographic dispersion. This therefore underpins the role of government and NGOs as potential seed market players.

The above review brings to the fore the explicit role of government, regulation for quality, role of NGOs, price, distance to seed source, farmer group associations, infrastructural aspects of transport and transaction costs[13] as being causal determinants of farmer's choice of market channel choices. In the following subsection, theoretical and empirical underpinnings of impact evaluation in relation to the topic under study are presented.

2.4 Impact of agricultural technology adoption

Assessing the impact of agricultural technology adoption and their dissemination pathways can assist with setting priorities, providing feedback to the research programs, guide policy makers and those involved in technology transfer to have a better understanding of the way new technologies are assimilated and diffused into farming communities, and show evidence that clients benefit from the research products (Manyong et al., 2001). This section therefore seeks to appraise the productivity and welfare impact of agricultural technology adoption. The section specifically examines both the theoretical and empirical considerations applied in the study of agricultural technology adoption impact on household productivity and welfare.

2.4.1 Theoretical considerations of impact of agricultural technology adoption

Several studies that estimate production and welfare impact show that agricultural technologies and innovations significantly improve household production and welfare (Asfaw, 2010; Asfaw et al., 2011; Kassie et al., 2011; Asfaw, 2012; Diagne et al., 2012; Kuntashula & Mungatana, 2013; Wellard et al., 2015; Khonje et al., 2015 and Magrini and Vigani, 2016). These studies have used different approaches with varying levels of rigour leading to unique impact estimates. For example, some studies reviewed have used profitability ratios and simple adopter and non-adopter comparisons to conclude that agricultural technologies improve household productivity and welfare (Wellard et al. 2015). Others have used robust identification strategies such as Propensity Score Matching and Endogenous Switching Regression analysis to control for selection and endogeneity bias (Asfaw et al., 2011; Kassie et al., 2011; Asfaw, 2012; Kuntashula & Mungatana, 2013, Khonje et al., 2015; and Magrini and Vigani, 2016).

[13] Transaction costs include costs resulting from distance to markets, poor infrastructure, high marketing margins, imperfect information, supervision and incentive costs (Sadoulet and de Janvry (1995).

In most of the studies reviewed, the choice of variables to measure welfare has been wanting to the extent that most studies conveniently pick on the easier but problematic income outcome variable ignoring consumption expenditure which is by far a better welfare measure. The literature reviewed for this study, as will be demonstrated in the sections that follow, concludes that most analysis has been partial, incomplete, and has used insufficient variable choices all of which lead to biased estimates that may potentially misadvise policy.

This study presents a holistic analysis of primary household cross-sectional data using various estimation methodologies in their varying rigour and attempts to use a correct choice of variables in distilling unbiased productivity and welfare impacts of cassava technology adoption in Uganda. To the extent that such a robust approach hasn't been applied to the cassava sub-sector in Uganda, at least to the best of my knowledge, it can be averred that the study findings make an original contribution to the existing body of organized knowledge in this regard and context. In the next sub-section, an elaborate exposition of the problem of endogeneity bias and the counterfactual outcomes framework is presented.

2.4.1.1 The problem of endogeneity bias and the counterfactual outcomes framework

Measurement of the productivity and welfare gain of adoption of agricultural technologies based on non-experimental observations is quite complex because of the need to find a counterfactual of intervention. In real life situation, it is impossible to observe the productivity and welfare outcomes of those farmers who adopted the technology had they not adopted during the same time. Furthermore, technology is not randomly distributed to the two groups of the households (adopters and non-adopters), but rather the households themselves decide to adopt or not to adopt based on several observable and non-observable characteristics. Therefore, adopters and non-adopters may be systematically different (Asfaw, 2010).

Against the above backdrop, impact evaluation using simple mean comparisons of welfare outcome variables (Ahimbisibwe and Mungatana, 2012; Wellard et al 2015) may lead to erroneous results because the adopters and non-adopters may not be the same prior to the intervention such that the expected difference in outcome variables between the two groups may not solely be due to adoption of the improved technology. Asfaw, (2010) and Kuntashula and Mungatana (2013) contend that the difference in farmer welfare between the two groups in the absence of technology adoption can be attributed to selection effect. Therefore the observed difference in welfare due to uptake of improved technologies includes the difference attributed to the selection effect or bias. It is argued that since the counterfactual of adopters is not known, it is difficult to estimate the magnitude of selection bias. By extension therefore, it is difficult to know the extent to which selection bias makes up the observed difference in outcomes between the adopters and non-adopters.

According to Asfaw (2010), the simplest approach to examine the impact of adoption of improved technologies on welfare outcomes would be to include on the welfare equation a dummy variable equal to one if the farm-household adopted the new technology, and then, to apply ordinary least squares. This approach, however, might lead to biased estimates because it assumes that adoption of improved technology is exogenously determined while it is potentially endogenous. The decision to adopt or not is voluntary and may be based on individual self-selection. Farmers that adopted may have systematically different characteristics from the farmers that did not adopt, and they may have decided to adopt based on expected benefits. Unobservable characteristics of farmers and their farms may affect both the adoption decision and the productivity and welfare outcomes, resulting in inconsistent estimates of the effect of adoption of the agricultural technology on household productivity and welfare. For instance, if only the most skilled or motivated farmers choose to adopt and we fail to control for skills and motivation, then according to Asfaw (2010), we will incur an upward bias. The solution is to explicitly account for such endogeneity.

Selection bias is controlled for through the creation of the counterfactual or a situation the adopting farmer would have experienced had they not adopted during the same simultaneous period. Using data from a cross sectional survey like the one that was conducted for this study, a counterfactual can be created through different approaches which include randomization in treatment assignment, Propensity Score Matching, using Instrumental Variable (IV) method, and Endogenous Switching Regression Modeling.

To start with, the selection effect disappears if treatment assignment is completely random (Asfaw et al., 2011; Asfaw, 2012; Taylor et al., 2012). The aim of randomisation is to make sure that the farms adopting the improved technologies and those not, have an equal probability of adopting the technology. This is because randomization eliminates the economic decisions that drive the treatment choice. In this study, this would imply that if participation in AIS initiatives or adoption of improved certified cassava seed is completely random, then the problem of selection effect disappears. However, this hypothetical situation cannot be achieved for this ex-post study because there was no control during the dissemination of the technology. Even still, it would be difficult and bordering on ethical issues to only give the technology to a selection of farmers and intentionally leave out others as controls in a situation where everyone is striving to benefit from the technology so as to get out of poverty. Thus the only seemingly plausible way out would be to explicitly account for such endogeneity using simultaneous equation models as suggested by Hausman, (1978).

However, the simultaneous equation modeling approach becomes problematic because it is inappropriate to use a pooled sample of adopters and non-adopters (with a binary indicator equaling to one for adoption and zero for non-adoption). This is because the approach would assume that technology adoption has an average impact over the entire sample of farmers, by way of an intercept shift, or that it raises the productivity of factors of production, by way of slope shifts in the outcome functions (Alene & Manyong, 2007).

Secondly, impact evaluations (Heckman et al., 1998; Blundel and Dias, 2000) can use matching methods to randomise the farmers and thereby create a plausible counterfactual. The matching technique works by creating randomness in treatment assignment on the assertion that if untreated individuals (non-adopters) have the same probability of participation as treated households (adopters), then the average welfare outcome estimates for the non-adopters becomes a good approximation of adopters' productivity and welfare outcome estimates had they not adopted (Madola, 2011). The Propensity Score Matching technique corrects the estimation of treatment effects by controlling for confounding factors based on the premise that the bias is reduced when the comparison of outcomes is performed using treated and control subjects who are as similar as possible in all ways before the treatment (Becker and Ichino, 2002).

The PSM method is one of the non-parametric estimation techniques that do not depend on functional form and distributional assumptions as is the case in OLS, Instrumental Variable (IV) and Heckman procedures (Bryson et al., 2002). Mendola (2007) and Magrini and Vigani (2016) argue that imposing any restriction – such as linearity and normal distribution for the error term - on the relationship between outcome variables and their determinants would be a strong assumption if not supported by theory. Further still, it is argued that matching does not impose any exclusion restrictions for identifying the selection process as in the case of IV and Heckman procedure (Magrini and Vigani, 2016). Jalan and Ravallion (2003) advise that finding such a good instrument – especially in cross-sectional datasets - is always complicated and its suitability is not fully testable.

The PSM method is intuitively attractive as it helps in comparing the observed outcomes of technology adopters with the outcomes of counterfactual non-adopters (Heckman et al., 1998). According to Asfaw (2010), the matching method can produce experimental treatment effect results when such data are not feasible and/or available. It also helps to evaluate programs that require longitudinal datasets using single cross-sectional dataset where the former does not exist as is the case in this study. The basic idea of the PSM method is to match observations of adopters and non-adopters according to the predicted propensity of adopting a superior technology (Rosebaum and Rubin, 1983; Heckman et al., 1998; Smith and Todd, 2005; Wooldridge, 2005). The main feature of the matching procedure is the creation of the conditions of randomized experiment in order to evaluate a causal effect as in a controlled experiment.

In agreement with Caliendo and Kopeinig (2005), Kuntashula and Mungatana (2013) summarise that matching is a form of randomisation that assumes away the selection effect by assuming that selection is based on observables. If all observable characteristics can be used to match adopters and non-adopters, then the causal effect of improved technology on farmer welfare indicators can be compared using like or similar groups of farmers. Although matching methods are intuitively easier, the assumption that selection bias is based only on observed characteristics is its main weakness. Matching cannot account for unobserved factors such as (skill, motivation, ambition and risk taking behavior) influencing adoption of technologies thereby leaving unsolved the problem of endogeneity due to unobservable covariates.

The third impact evaluation approach to solve the selection and endogenous problem is the Instrumental Variable (IV) approach in which a randomly assigned variable (instrument) that would not affect the outcome variable except through its effect on the treatment can be used. According to Kuntashula and Mungatana (2013), this becomes vital when the estimation is concerned with correlation of the treatment variable (e.g. improved certified cassava seed adoption or participation in AIS initiative) with the errors. The instrument should be correlated with adoption of improved certified cassava varieties but uncorrelated with productivity and farmer welfare so that by extension it should not be correlated with the error term. Instrumental variable estimation is a good identification strategy to estimate causal relationships in theoretical work since there are practical difficulties when applying it to an empirical study. The main weakness with this approach is that it is very difficult to find such an instrument. As earlier mentioned, it is difficult to find good instruments that are not correlated with the endogenous variable or the error term. If the instruments are weakly correlated with these factors, biased and inconsistent estimates may be produced. Even if good instruments are utilized in a model, it is hard to assess the extent to which the treatment of endogeneity affects the magnitude of the outcome estimates.

The fourth approach is called the Heckman two step selection procedure which is closely linked with the Instrumental Variable approach. Heckman (1979) proposed an alternative model that addresses the selection problem arguing that an estimation on a selected subsample results in sample selection bias. Also called the sample selection model, it involves two equations: firstly, the regression equation that considers mechanisms determining the outcome variable and secondly, the selection equation considering a portion of the sample whose outcome is observed and mechanisms determining the selection process. While the first estimates the probability of observing a positive outcome (known as the selection or participation equation), the second estimates the level of participation conditional on observing positive values (known as the conditional equation) (Dow & Norton, 2003). The model assumes that different sets of variables could be used in the two-step estimations. Kennedy (1998) however states that the Heckman Selection model does not perform well when: the error terms are not distributed normally; the sample size is small; the amount of censoring is small; the correlation between errors of the regression and selection equations is small; and the degree of collinearity between the explanatory variables in the regression and selection models is high.

Finally, the most robust impact estimation approach is called the Endogenous Switching Regression modeling (ESR) approach proposed in Madada and Nelson (1975), Freeman, et al. (2001), Alene and Manyong, (2007), Asfaw (2010) and emphasized in Madola et al, (2011), Kuntashula and Munagata, (2013) and further in Shiferaw et al. (2014), Kassie et al. (2015) and Magrini and Vigani (2016). The ESR uses maximum likelihood estimation (MLE) techniques to predict the potential outcomes the adopter (or non-adopter) of a technology would get in the two regimes of either adopting or not. The model is comprised of the selection equation or the criterion function and two continuous regressions that describes the behaviour of the farmer as he faces the two regimes of adopting the improved technology or not. According to Freeman et al. (2001) and Alene & Manyong (2007), the ESR accounts for both endogeneity and sample selection and allows interactions between adoption and other covariates in the outcome function.

Based on the above discourse, this study used Propensity Score Matching (PSM) for binary treatment effects complimented with Endogenous Switching Regression modeling (ESR) because of their heightened robustness as detailed in this section. The next section presents a detailed appraisal of previously adduced empirical evidence of productivity and welfare impacts of agricultural technology adoption on smallholder farmers with a view of further crystallizing the research gap.

2.4.2 Empirical considerations of impact of cassava technology adoption

Ayoade (2013) studied the adoption impact of improved cassava varieties on the social life of rural farmers in Oriire Local Government Area of Oyo State in Nigeria using the before and after comparison of the housing condition, health condition, mobility status, safe water consumption, ownership of communication gadgets and toilet facilities of the adopters. The study relies on recall to capture the before condition and uses respondent opinion judgments on the state of the parameters studied. Moreover the study relied on a very small sample of 80 households. Such an approach may lead to inaccurate conclusions being drawn as to the exact cause of the welfare improvements especially when it does not seek to address the attribution question empirically. Several other factors, as have been considered in this study's analysis, could have resulted into the welfare improvements registered as earlier discussed. Further still, this study has included pre-adoption data on parameters that lead to reverse causality such as wealth and asset status, access to extension and social capital. Pre-adoption data has been used in the regressions to mitigate reverse causality challenges that would result from use of post-adoption data in which case it would be difficult to tell whether it is technology adoption that causes the observed wealth or it is the wealth that causes technology adoption.

In their study on the implications of agricultural policy on welfare of cassava farmers in Nigeria, Asogwa et al. (2012) found out that farmers who had adopted the improved cassava varieties had improved their yields, sold more volumes, earned higher incomes and were generally living more fulfilling livelihoods. The study however relied on mean comparisons of the outcome variables measured at baseline and endline of a specific technology promotion program. By relying on methodologies that based on analysing pre- and post-adoption parameters only, the control of other factors in influencing welfare changes was not considered, making the conclusions potentially spurious.

Amao and Awoyemi (2010) studied the adoption of improved cassava varieties and their welfare effect on producing households in Osogbo Agricultural Development Programme zone of Osun Nigerian State. The study estimated household welfare using Foster- Greer-Thorbecke (FGT) (1984) poverty measures and Tobit regression model for adoption determinants. The results showed that poverty was higher amongst households who were non adopters of improved cassava varieties. The study however did not control for selection and endogeneity bias which could potentially lead to spurious estimates.

Adekemi Obisesan (2014) studied gender differences in technology adoption and welfare impact among Nigerian farming households. Changes in poverty of adopters and non-adopters were achieved by using the Foster- Greer-Thorbecke (1984) class of poverty measures (FGT). The study further used Propensity Score Matching to generate a counterfactual based on observable covariates. Empirical evidence from the study revealed a higher adoption level and impact of improved cassava technology on the male farmers. They reported that though there was reduction in poverty indices of both male and female adopters due to adoption of the technology, the impact was higher on the poverty indices of males. By relying only on observable characteristics in Propensity Score Matching, the study ignores the fact that the adopters and comparison groups may differ in unobservable characteristics which may substantially manifest themselves in the welfare outcomes. To the extent that this was not controlled for, the reliability of the results calls for further improvement which this current study sought to provide.

Ilemona et al. (2011) assessed the economic impact of improved agricultural technology adoption on cassava productivity in Kogi State of Nigeria using before and after comparison of the revenues accrued from cassava sales and testing the statistical significance difference by use of chi-square. The results showed that revenue of farmers after the adoption of the innovation are higher than revenue generated before adoption. The study concludes that improved cassava technology adoption improves productivity as well as the socio-economic transformation of cassava farmers from the shades of poverty. Both findings and conclusions of the study by Ilemona et al. (2011) would be more reliable had they controlled for selection and endogeneity concerns.

Several impact studies of agricultural technologies have estimated aggregate economic benefits through extrapolation of farm level yield or income gains using partial equilibrium simulation models such as the economic surplus model (Alston et al., 1995). For example Alene et al (2013) estimates the economic impacts of cassava research and extension in Malawi and Zambia over the period 1990-2008 using data from sample household surveys, secondary data, planting material use production records and a series of cassava improvement experiments conducted in the two countries. Their results indicate that multiplication and distribution of clean cassava planting materials generated a modest rate of return of 24%, which was consistent with an earlier rate of return estimate of 9 to 22% for cassava improvement in developing countries. Analysis of the ex-ante impacts of current and future investments in cassava improvement showed that cassava improvement research that focuses on the development and dissemination of varieties with highly preferred consumption and industrial attributes would yield a greater rate of return of 40%.

Motivating the study results, Alene et al (2013) argue that technological change due to research in agriculture increases the yield or reduces the cost of production once the new technology is adopted. They contend that if the new technology is yield increasing, the producer sells more of the good in the market and that if demand is downward sloping, the price decreases. Technology adoption reduces the per-unit cost of production and hence shifts the supply function of the commodity down and to the right. If the market for the commodity is perfectly competitive, this will lead to an increase in the quantity exchanged in the market and a fall in price. As a result, consumers benefit from the price reduction and producers may benefit from selling a greater quantity. While the economic surplus method is a widely used procedure for economic evaluation of benefits and costs of a technological change, it too fails to control for confounding factors thereby producing misleading estimates about causality. Both biophysical variables as well as socioeconomic characteristics of farmers could be important in so far as increasing productivity and welfare is concerned.

Enterprise budgeting was used by Franzel (2004) and Ajayi et al. (2007) through farm modeling to assess the impact of adopting improved agricultural technologies in Zambia. The technologies were found to have a positive effect on household annual maize incomes. These studies used net present value and cost benefit ratio criteria to arrive at this conclusion. While these criteria are indeed important and beneficial in estimating profitability, Kuntashula and Mungatana (2013) argue that they fall short of measuring causality since covariates that equally would have led to an increase in maize yields and incomes were not controlled for.

In probably the only recent studies done on cassava in Uganda so far to the best of my knowledge, Bua (1998), NRI (2014), Wellard et al. (2015), used mean comparisons of outcomes of production, yields, incomes, food security and economic status to conclude that modern cassava varieties and technologies improved the adopting farmers' welfare as measured through incomes. As earlier discussed however, this methodology, which was informed by the analysis scope imposed on the studies, did not control for both observable and unobservable farmer characteristics in their impact estimation thereby suffering the selection and endogeneity bias problems earlier discussed.

2.5 Conclusion

From the foregoing literature review, limited inquiry has been done on the empirical performance of AIS interventions in livelihood improvements of cassava growing communities of rural Uganda. Where an attempt has been made, robust methodological approaches have not been applied to the cassava commodity. The literature appraisal also reveals that methodologies used to estimate productivity and welfare impact of cassava technologies were not robust enough in as far as they did not follow proper identification strategies in isolating the causal effect of the intervention. The review confirms that the studies failed to move beyond estimating incremental cassava yields and revenues, crop incomes and assets that adopters supposedly gain. Since it is factually established in the field of impact evaluation that several biophysical as well as socioeconomic factors both observable and unobservable could equally have an influence on farmer outcome variables, then, controlling for them becomes a necessity.

In summary, this study submits that a research problem exists backed by a research gap manifested in the inadequacies identified in the multitude of previous studies done on impact estimation of agricultural technology adoption. These inadequacies include, inter alia: (a) qualitatively assessing impact of AIS on farmer livelihood outcomes without sufficient application of robust quantitative analytics (b) assessing the effects of single technologies (usually only seed genetic improvement), disregarding the impact of other important complimentary innovations such as seed certification; (c) evaluating the impact of agricultural technologies using sub-national location specific datasets at district or regional level thereby disregarding nationally representative datasets; (d) limiting the analysis to a single measure of productivity (usually grain yield) or welfare (incomes or consumption expenditure) disregarding the fact that both productivity and welfare are multi-dimensional and complex phenomena which cannot be understood through single indicators; (e) estimating impact of technology adoption using less rigorous estimation methodologies that lack frontier robustness checks; (f) shunning root crops especially cassava whose piece-meal harvesting regimes occasion enormous yield data challenges and instead conveniently over-studying grain crops whose data challenges are limited.

Consequently, in its empirical estimation of causality and impact, this study used methodologies in order of robustness starting with mean comparison of outcome variables, then application of Ordinary Least Squares (OLS) regression, followed with binary treatment effects Propensity Score Matching (PSM) using nearest neighbor (NNM), kernel based matching (KBM), and radius matching (RM) propensity score estimation techniques. Cognizant of the fact that the endogeneity bias due to unobservable covariates still persists even with use of PSM, the analysis was extended by applying the Endogenous Switching Regression Modeling (ESRM) technique and thereafter, a concluding section triangulating impact estimates generated from all the different approaches used. While the magnitude of estimated effects may vary across estimation methods, this study seeks to test if results are consistent across estimation methods as one of the hypotheses under investigation.

The novelty of this study approach is to empirically adapt and apply the most robust impact estimation techniques capable of yielding reliable empirical evidence on the previously neglected cassava commodity in Uganda. To the extent that such a comprehensive analysis approach hasn’t been applied to study the impact of cassava innovations in Uganda, it is submitted that this forms the cornerstone of the proposed study and presents the original contribution to the existing body of organized knowledge. The next chapter presents the conceptual framework, methodological approach, results, discussions, conclusions and policy recommendations of objective 1.

3 CHAPTER THREE: IMPACT OF PARTICIPATION IN CASSAVA AIS ON PRODUCTIVITY AND WELFARE

3.1 Chapter summary

One of the functions of Agricultural Innovation System (AIS) initiatives is to increase stakeholder interaction and learning through knowledge and experience sharing. However, participation in AIS initiatives through membership of Agricultural Innovation Platforms (AIPs) is not universal. Indeed, the descriptive statistics indicate that AIP members differ from non-AIP members in many aspects such as education levels, wealth status, access to extension services and training participation. Using probit modeling, this study estimated the causal determinants of household participation in AIS initiatives through AIP membership. The results indicate that the households who received extension services prior to AIS intervention commencement were 49% more likely to join AIPs. In addition, educated households and those that belong to other groups were 1.8% and 17.5% more likely to join AIP initiatives than their less educated counterparts and those that do not belong to other groups respectively. Propensity Score Matching (PSM) techniques were also used to estimate the impact of AIP membership on productivity and welfare. The study used cassava stem and root yield as measures of productivity while household welfare was measured using cassava cash income and household total consumption expenditure both adjusted to per capita levels using Adult Equivalent Units (AEUs). PSM results reveal that participation in AIS initiatives through AIP membership positively and significantly increases cassava stem yield by 12.4 bags/acre (30.63 bags/ha), per capita cassava cash income by UGX 2.2 million and per capita consumption expenditure by UGX 207,000. In this study, it was also found that AIP members were more likely to adopt production enhancing inputs such as the use of improved certified seed. From a policy perspective, the findings of this study would support programmes that enhance AIP participation since they in turn improve technology adoption, productivity and household welfare. One major way of enhancing AIP participation is through awareness creation using other existing programs such as extension services and farmer group memberships.

3.2 Introduction

As a preliminary investigative procedure, the study analyzes descriptive statistics to gain an understanding of inherent significant socio-economic characteristics of the respondents and variable mean comparisons between AIS participants (by way of their involvement and participation in the formal cassava programme initiatives) and non-AIS participants. With this understanding, the study then attempts to examine the determinants of farmer participation in the Agricultural Innovation System (AIS) initiatives through participation in Agricultural Innovation Platform (AIPs) and then further distils the impact that the characterized AIS initiatives have had on cassava productivity and household welfare of the cassava growing communities. To achieve this, a more robust causal-effect identification strategy (Propensity Score Matching) was adapted to effect randomization using the counterfactual outcomes framework.

Related data was collected from cassava farmers that were participating in any of the cassava AIS initiatives[14] (Cassava Seed Entrepreneurship (CSE) initiative and the Multi-Stakeholder Innovation Platforms initiative under the Cassava Regional Center of Excellence (CRCoE) program that has been running since 2010); and those that did not participate in any. The non-AIS respondents formed a pool from which a counterfactual was constructed using the Propensity Score Matching (PSM) techniques following the works of Asfaw (2010); Madola (2011); Mapila et al. (2012); and Kuntashula and Mungatana (2013). This then enabled mean comparison of outcome variables between AIS and non-AIS groups thereby showing impact of participation in AIS initiatives. While impact on productivity was estimated using cassava stem yield (bags/acre) and cassava root yield (Kgs/acre) as the main outcome indicators, per capita household consumption expenditure (UGX'000) and per capita cassava cash income (UGX'000) were estimated as the main welfare outcome indicators. Having understood the (a) AIS interventions that operated in the area through AIS characterization, (b) the causal determinants of AIS participation,

[14] It is worth noting that the characterized AIS initiatives are not necessarily perfect cases of an Agricultural Innovation System but rather had elements of AIS. This is in light of the fact that AIS is a wide concept with numerous elements and remains a theory that is still evolving in different dimensions. For purposes of this study, the characterized AIS case studies under assessment are referred to as AIS case studies in light of this explanation.

and (c) impact of AIS participation on household productivity and welfare; the study concludes the chapter by suggesting policy recommendations on AIS functionalities.

3.3 Research objective and questions

To examine the impact of cassava Agricultural Innovation Systems (AIS) interventions on productivity and welfare of cassava growing communities

3.4 Research questions

1. What are the differences in socio-economic characteristics between farmers participating in AIS initiatives and those that are not?
2. What are the factors that determine participation of farmers in Agricultural Innovation Systems interventions?
3. What is the impact of cassava AIS interventions on the household productivity and welfare of cassava growing communities of rural Uganda?

3.5 Hypothesis tested

Livelihood outcomes (cassava productivity and household welfare) of cassava farmers participating in Agricultural Innovation Platforms (AIPs) are higher compared to their counterpart non-participants.

3.6 Background

Literature (Spielman, 2005; World Bank, 2006; Hall, 2007; Triomphe et al., 2007; FARA, 2008; Martin, 2009; Spielman et al., 2009; Sanginga et al., 2009; Klerkx et al., 2010; Madola, 2011; Mapila et al., 2012; Wellard et al., 2013) presents a convergence of ideas in defining Agricultural Innovation Systems (AIS) as being the participatory generation, dissemination, and utilization of agricultural-related knowledge or technology by a spectrum of actors ranging from scientists, farmers, input suppliers, traders, stockists, extension workers, the private sector and other interested stakeholders. Individual actors are motivated by their own interest which is part of a wider shared common or mutual interest. The AIS approach therefore assumes the value chain formation in its multi-stakeholder dynamic.

Accordingly, Alacho, (2003) and Clesensio, (2003) posit that the National Agricultural Research Organization (NARO) of Uganda introduced the innovation systems concept to make research relevant and impact oriented. While reviewing the reform process in NARO, Hagmann and Blackie (2002) noted that in Uganda, as in other African countries, the process of generating knowledge and technology had become more scientific and academic and thus remained separated from the users. The division of research and extension had become increasingly strong and inhibited effective feedback loops in the system (Sanginga, 2009). A new initiative to reform NARO therefore began in 2003 as an initiative of NARO, Makerere University (MAK) and the International Center for Development-oriented Research in Agriculture (ICRA) with support from DFID. The initiative endeavored to build effective research systems within NARS that embrace the innovation systems concepts, integrated agricultural research for development (IAR4D) and Integrated Natural Resource Management (INRM) approaches, thus addressing the multifaceted problems and needs of farmers and enabling stakeholder participation (Sanginga, 2009). Figure 3.1 is a graphical representation of an Agricultural Innovation System interface with household livelihoods.

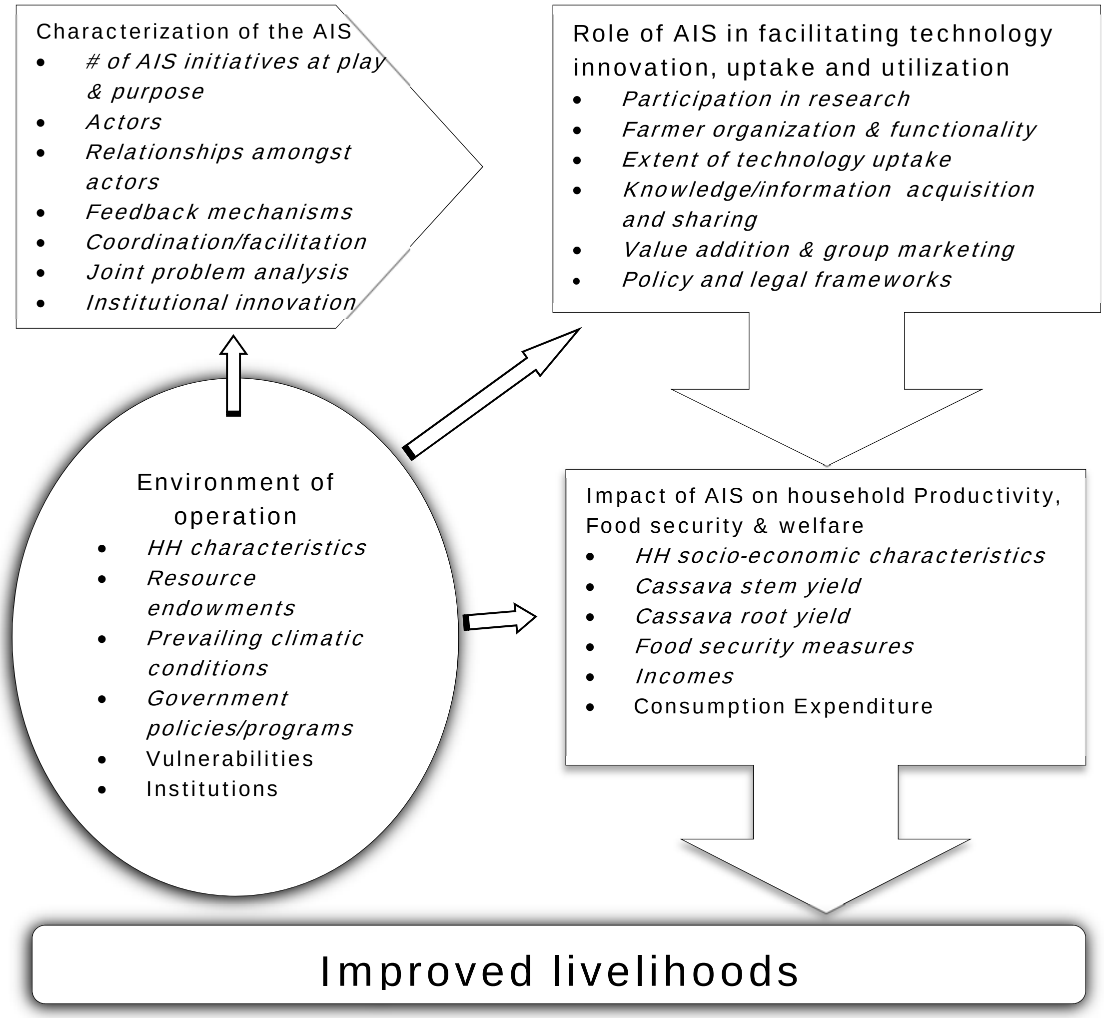

Figure 3.1: Representation of an Agricultural Innovation Systems interface with household livelihoods

The figure illustrates a decomposition of the elements of an AIS and how they interact with individual and external environments to facilitate technology innovation, uptake and utilization leading to livelihood outcomes

(Author's compilation)

3.7 Characterization of the cassava AIS initiatives in Uganda

3.7.1 Introduction

At the onset, Key Informant Interviews (KIIs) were held with NARO-NaCRRI cassava researchers, government and non-government extension officers, NGOs that have been involved in the cassava AIS initiatives and local government agricultural officials. These KIIs helped to deepen the understanding of the cassava AIS initiatives that were operating in the districts identified for this study. Lists of actively functional Multi-stakeholder Agricultural Innovation Platforms (AIPs) at NaCRRI and District Local Governments (DLGs) provided the required sampling frames that informed the sampling design for this study.

A comprehensive characterization of the active AIPs in the identified study areas was carried out through KIIs, FGDs and Case Studies. These were used to characterize the AIS initiatives in the study area by analyzing the innovation behaviors and processes that had been obtaining in the communities, the prevailing environment, policies and institutional facilitation setups. Following the works of Hall et al. (2007), Martin (2009), Madola (2011) and Wellard et al. (2013), the study analyzed AIS actors and their roles, attitudes and practices, patterns of interaction, vulnerabilities, facilitation mechanisms and the enabling environment for innovations. Focused Group Discussions (FGDs) were, as recommended by CIDA (2003), facilitated using After Action Review (AAR), a participatory technique that helps to structure collective reflection, analysis and learning by talking, thinking, sharing and capturing the lessons learned about a completed activity before they are forgotten. Sanginga et al. (2009) posit that AAR recognizes the explicit interests, different perspectives, and judgments of different stakeholders, and provides opportunities for collective learning and reflexivity. As argued in Sanginga et al. (2009), case studies emphasize detailed contextual analysis of a limited number of events or conditions and their relationships. When systematically implemented, the case study methodology can establish reliability and generality of findings even with a small number of cases. This study used both KIIs and FGDs to characterize AIS initiatives and their impacts on household productivity, food security indicators and welfare (Martin, 2009).

3.7.1.1 AIS Case study I: Cassava Regional Center of Excellence AIS initiative

Using the findings from the FGDs and KIIs, this study was able to establish that following the devastating viral effects of the Cassava Mosaic Disease (CMD) and Cassava Brown Streak Disease (CBSD) in Uganda around early 2000s, renewed calls to develop more resilient cassava varieties ensued under the AIS research framework. The NARO National Cassava Research Programme instituted Agricultural Innovation Platforms in most of the CBSD and CMD affected regions of Uganda with the aim of bringing farmers together with the researchers and other interested stakeholders to find lasting solutions to cassava production problems. Under this arrangement, cassava technologies were developed through Participatory Plant Breeding (PPB) and Participatory Variety Selection (PVS) in a system that encouraged interactions between NGOs such as Catholic Relief Services (CRS), World Vision (WV); local government authorities; market players supplying war-torn Democratic Republic of Congo (DRC) and Southern Sudan; and local processors. The researchers would rely on the farmers' monitoring for continuous variety performance reports. The initiative was a great success with the key success drivers being development of technologies that met specific farmer needs but also satisfied farmers' other criteria, with rapid multiplication, distribution and uptake (Bua,1998).

Building on this historical success, the East African Agricultural Productivity Project (EAAPP) launched a cassava research initiative under the framework of the Cassava Regional Center of Excellence (CRCoE) in 2010. Since then, this CRCoE AIS initiative has been operating through an agricultural innovation systems approach involving national and regional actors brought together under one commodity-cassava. National and regional actors interacted innovatively to generate over 11 new cassava technologies and innovations that were highly adopted by farmers leading to visible improvements in their livelihoods (Wellard et al., 2015). One unique element of this AIS initiative is the cross-fertilization of ideas and free exchange of cassava germplasm across national borders and the regional sharing of technologies amongst the four countries (Ethiopia, Kenya, Tanzania and Uganda) that implemented the regional EAAPP project. The CRCoE AIS initiative mainly operated in the districts of Wakiso, Mukono, Mbale, Soroti, Amuria, Lira, Apac, Dokolo, Kiryandongo, Masindi and Kabarole– all of which were covered in this study.

3.7.1.2 AIS Case study II: Cassava Seed Entrepreneurship (CSE) AIS initiative

According to Zerbe, (2001), African governments and development partners recognized the importance of quality seeds in 1970s leading to establishment of a highly subsidized formal seed sector, organized mainly around seed parastatals. This however had limited success due to issues of financial sustainability and the lack of small-scale farmers' involvement in both variety development and seed supply chains. The 1980s' structural adjustment programmes (SAPs) saw a policy shift to disbanding of the parastatals and encouraging private sector development. This new paradigm, according to Zerbe (2001); Daniel and Adentumbi (2004) orphaned vegetatively propagated crops like cassava and other minor crops as profit driven commercial seed companies focused on hybrid maize and high value vegetables in pursuit of high potential markets. Cassava seed was left out of the formal seed sector and would only be supplied through relief purchases by development and relief operations.

In their scholarly article, Seboka and Deresa (2000) report that NGOs, development and relief agencies became interested in the seed sector and supported community-based seed production and supply in the 1990s with the aim of transforming local community seed producers into high quality seed producers. This intervention successfully improved access to seeds in remote areas and to poorer farmers. Despite renewed efforts to improve seed access through targeted support to private sector and regional seed policy harmonization to ease trade, Tripp, (2003) and Rubyogo et al. (2007) reported that companies continued to focus on non-vegetatively propagated seed rather than the whole range of crop species which constitute the backbone of resource-poor farmers' food security. Without any other recourse, a section of farmers have continuously depended on informal cassava seed markets that normally lack protocols, standards, and guidelines as well as operating without inspections and certification by the mandated authorities. As a consequence of this unregulated cassava seed supply system; distribution and planting of latently diseased planting material has thrived unabated, as evidenced in most gardens established using materials supplied from unregulated sources (McQuaid et al., 2016). Thus, the need to build the cassava seed supply system as well as to manage cassava pest and disease challenges for increased productivity led to the birth of the Cassava Seed Entrepreneurship (CSE) initiative.

The CSE initiative is a research for development intervention by NARO-NaCRRI that uses Agricultural Innovation Systems concepts to establish a functional commercialized cassava seed delivery system in Uganda by bringing together various players in the cassava seed value chain. These AIS actors include: cassava researchers from NaCRRI that provide popular cassava varieties of requisite traits (developed and produced with farmers in a participatory research approach involving Participatory Plant Breeding and Participatory Variety Selection); NaCRRI agronomists that train CSEs in cassava agronomic husbandry techniques; cassava farmers that serve as cassava seed entrepreneurs (CSEs); cassava seed multipliers that operate through tissue culture (TC) mass production and farmer field seed bulking (BioCrops and NARO-ZARDIs); NGOs that provide capacity building in business and market linkage dynamics (MEDA, Afrii and CHAIN); the National Seed Certification Services (NSCS) agency of the Agriculture Ministry that provides seed inspection and certification services, and finally the certified cassava seed buyers.

The CSE initiative has been operating in the districts of Mukono, Soroti, Amuria, Lira, Kiryandongo, Masindi, and Kabarole essentially covering the major areas that were studied for this thesis. The CSE AIS initiative envisaged that the CSEs would create a functional cassava seed system that would help in bridging the potential cassava seed supply and yield gaps. Like the Enabling Rural Innovation (ERI) initiative of CIAT described in Sanginga et al (2009) and Mapila et al. (2012), the CSE AIS initiative aims to create an entrepreneurial culture in Uganda's cassava rural communities by enabling farmers to produce and sell certified cassava seed thereby creating a commercialized functional cassava seed delivery system in Uganda. The CSE AIS initiative builds the skills and knowledge of communities, local service providers, local and central government agricultural inspectors, individual farmers and farmer groups to engage effectively in markets. A market orientation is emphasized which enables smallholders to link themselves successfully to potential markets, with support from NARO Zonal Agricultural Research and Development Institutes (ZARDIs) as supply quality guarantors. Next is a graphical representation of the CSE AIS Initiative.

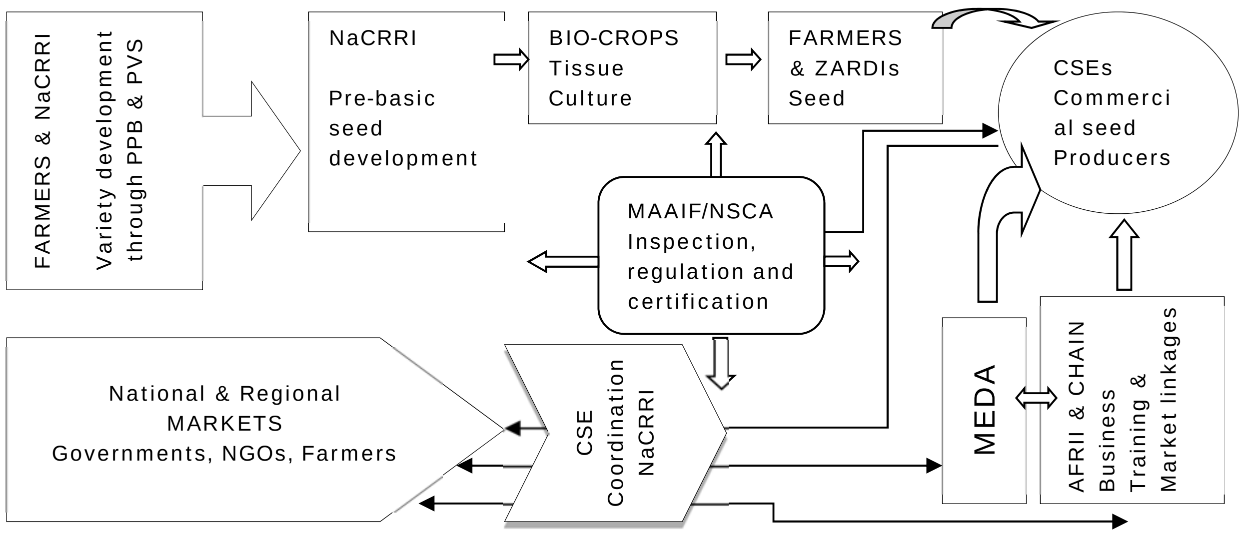

Figure 3.2: Graphical representation of the CSE AIS Initiative
(Source: Author's compilation)

3.8 Methodology

3.8.1 Introduction

Spielman (2006) noted that the AIS framework was facing several methodological limitations in its application to developing country agriculture and that rigorous qualitative and quantitative methods were only a preserve of industrialized countries leaving developing countries with methodological toolkits consisting of descriptive case studies typically drawn from an action research or stakeholder analysis exercise. The methodology employed by this study shows how scholarly advancements have evolved to close the gap in less than a decade.

Three years after Spielman's (2006) assertion, Martin (2009) observed that outcome and impact evaluation of AIS interventions remains rather complex since the nexus of partnerships and institutional interrelationships within the holistic IAR4D paradigm cannot be replicated as a 'treatment' that would enable direct comparative assessments. The same author observes that comparisons are relatively easier at the level of research sites, but less straightforward at the level of institutional change and innovation platforms. Martin (2009) further proposes a combination of impact pathway mapping, individual and group monitoring of institutional and behavioral changes and participatory assessments whose design, the study argues, is a practical challenge. This study attempts to apply a robust methodological approach that seeks to alleviate Martin's (2009) concerns.

3.8.2 Data analysis and computational approaches

Descriptive statistics are used to analyze the socio-economic characteristics of AIP and non-AIP participants. Determinants of farmer participation in Agricultural Innovation System platforms are studied using probit modeling while the impact of AIS participation on household productivity and welfare are evaluated using the robust quantitative causal-effect non-parametric identification econometric strategy called Propensity Score Matching (PSM). For ease of reading, data collected and the description of the variables used in this study as well as the empirical data analysis strategies for (a) studying determinants of AIS participation (probit model) and (b) productivity and welfare impacts of AIS participation (Propensity Score Matching) are presented in subsequent sections respectively.

3.9 Descriptive statistics of AIS and non-AIS participants

3.9.1 Introduction

Based on a household survey of 609 respondents studied following the sampling procedure elaborated in section 1.5, this sub-section presents the characteristics of the households which participated in the AIS initiatives and compares the same characteristics with those of the households that didn't participate in the AIS initiatives. As a preliminary investigative procedure, the study presents descriptive statistics to gain an understanding of inherent significant socio-economic characteristics of the respondents. Table 3.1 presents a summary of the socio-economic characteristics of the respondents and variable mean comparisons between AIS participants and non-AIS participants.

Table 3.1: Household characteristics of AIP and non-AIP members

VARIABLE	AIP Member	SD	Non-AIP Member	SD		t-test
Variables	Mean (A)		Mean (B)		(A-B)	P-VALUE
Productivity outcomes						
Parcel stem yield (bags/acre)	54.41194	154.0419	33.30973	30.49546	21.10221***	0.003
Parcel root yield (Kgs/Acre)	2724.727	2603.918	2725.623	2086.684	-0.896	0.997
Cassava technology adoption						
1 if used improved uncertified seed	0.4136126	0.493775	0.3289474	0.470273	0.084665**	0.036
1 if used improved certified seed	0.3403141	0.47506	0.1015038	0.302279	0.23881***	0.000
1 if used local seed	0.2460733	0.431854	0.5695489	0.495605	-0.32348***	0.000
Adoption intensity						
Area improved seed (Acres)	0.7931937	1.860696	0.3639513	0.679067	0.429242***	0.000
Area certified seed (Acres)	1.18534	2.74555	0.1299157	0.615528	1.055424***	0.000
Area local seed (Acres)	0.2089005	0.434226	0.4979494	0.729055	-0.28905***	0.000
n=534						
Welfare outcomes						
PCHHConsumption Exp'000 (UGX)	1410.389	1677.961	993.1707	715.5891	417.2183***	0.000
PCHHCassIncome'000 (UGX)	2544.672	9236.873	260.7577	562.4471	2283.914***	0.000
Food security measures						
# of Meals Per Day	2.62987	0.70434	2.50989	0.636111	0.11998*	0.049
1 if Food deprived in 2015	0.2662338	0.44343	0.3692308	0.483128	-0.103***	0.019
# of months food insecure	0.6688312	1.353066	0.7868132	1.331027	-0.11798	0.344
Wealth status measures						
PCTotAsset value'000 (UGX)	11827.74	31427.9	6703.398	18669.97	5124.342***	0.016
HH Total Land operated (Acres)	47.56505	322.8675	9.943918	37.14352	37.62113***	0.015
TLU 2015	4.987273	7.384281	2.248	2.824075	2.739273***	0.000
FGT Poverty outcome variables						
Head count index	0.554		0.730			
Poverty gap index	0.192		0.304			
Poverty severity index	0.089		0.157			
Communication enablers						
Has TV 2015	0.1883117	0.392236	0.0857143	0.28025	0.102597***	0.001
Has Radio 2015	0.7857143	0.411665	0.6813187	0.466478	0.104396***	0.014
Has Mobile Phone 2015	0.8571429	0.351069	0.8131868	0.390191	0.043956	0.216
Transport means						
1 if HH has motorcyle in 2015	0.2987013	0.459182	0.1472527	0.354748	0.151449***	0.000
1 if HH has bicyle in 2015	0.8571429	0.351069	0.7384615	0.439956	0.118681***	0.000
1 if HH has motorvehicle in 2015	0.0649351	0.247215	0.0241758	0.153764	0.040759***	0.017
Group membership and networks						
1 if HH belongs to group	0.9415584	0.235342	0.7076923	0.455324	0.233866***	0.000
# of Pple reliable upon	34.5974	57.0282	23.16923	33.96675	11.42817***	0.003
# of Pple reliable upon for seed	18.44156	43.17225	15.05714	27.45724	3.38442	0.259
Farmer perceptions						
1 if satisified with improved vars	0.7662338	0.424606	0.5516484	0.497873	0.214585***	0.000

1 if satisfied with seed inspection	0.1948052	0.397343	0.0769231	0.266763	0.117882***	0.000
1 if trust farmer channels	0.4155844	0.49443	0.589011	0.492555	-0.17343***	0.000
1 if trust govt channels	0.6883117	0.464694	0.3978022	0.489983	0.29051***	0.000
1 if trust NGO channel	0.4220779	0.495502	0.2285714	0.420375	0.193507***	0.000
1 if trust CSE channel	0.3896104	0.489253	0.2505495	0.433806	0.139061***	0.001
Access to credit and extension						
1 if accessed credit in 2015	0.5974026	0.492021	0.4087912	0.492152	0.188611***	0.000
1 if trained on improv vars 2015	0.2857143	0.453228	0.043956	0.205223	0.241758***	0.000
1 if trained on agronomy 2015	0.4220779	0.495502	0.0593407	0.236521	0.362737***	0.000
1 if received extension 2015	0.7207792	0.45008	0.1362637	0.343446	0.584516***	0.000
1 if received govt extension 2015	0.3831169	0.487733	0.0681319	0.252249	0.314985***	0.000
1 if trained on improv vars 2010	0.3116883	0.464694	0.0373626	0.189858	0.274326***	0.000
1 if trained on agronomy 2010	0.3636364	0.482615	0.0527473	0.223775	0.310889***	0.000
1 if received extension 2010	0.5584416	0.498193	0.1054945	0.307528	0.452947***	0.000
1 if received govt extension 2010	0.3506494	0.47873	0.0593407	0.236521	0.291309***	0.000
Demographic characteristics						
Age of HH head	48.55263	13.41482	44.83482	14.1663	3.71781***	0.005
# of School Yrs of HH Head	9.644737	4.202503	7.691964	4.487988	1.952773***	0.000
Family size	7.662338	3.276418	7.072527	2.940154	0.589811**	0.037
1 if HH head is female	0.1103896	0.314397	0.1978022	0.398781	-0.08741***	0.014
Decision-making						
Husband decides	0.6038961	0.490682	0.5253863	0.499907	0.07851**	0.091
Husband and wife decides	0.2207792	0.416125	0.2295806	0.421028	-0.0088	0.822
All decide	0.038961	0.194134	0.0242826	0.154095	0.014678	0.341
Others decide	0.0324675	0.177817	0.0927152	0.290354	-0.06025***	0.016
n=455						

**** p<0.1 is significance at 10%; ** p<0.05 is significance at 5%; and *** p<0.01 is significance at 1%***

Table 3.1 presents the characteristics of AIP members and compares them with those of non-AIP members. From the statistics, cassava stem[15] productivity is higher among the AIP participants than their non-participating counterparts. The AIP participants harvested 54 bags of cassava stem per acre while the non-participants harvested 33 bags per acre and the difference is significant at 1 percent. On the technology adoption, there were significantly more AIP members who adopted improved certified and improved uncertified seed compared to non-AIP members. Indeed, 34% of AIP members reported to have planted improved certified seed compared to only 10% of the non-AIP members. Likewise, 41% of AIP members planted improved uncertified seed compared to 32% on non-AIP members. Conversely, more non-AIP members (50%) planted local seed compared to AIP

[15] Stem yield is measured in bags harvested per acre. A bag of stems means a labeled perforated bag of dimensions 110cm x 80cm filled with 500 pieces of cassava mature stakes of 20-25cm length (MAAIF, 2015).

members (25%). This could either be because non-AIP members preferred local varieties or did not have access to improved varieties.

In addition to the adoption dummies of whether the household used or did not use a given seed category, Table 3.1 also provides the statistics on adoption intensity and consistent with the adoption dummies, AIP members had higher adoption intensities of improved certified and uncertified seed varieties and less of local seed compared to non-AIP members. The use of improved seed varieties might be the reason as to why the stem yield is higher among AIP members and this is examined more in the robust estimation strategies in the subsequent sub-sections.

The welfare measures are high among AIP participants compared to the non-participants. For instance, the household per capita consumption expenditure is significantly high among the AIP participants (UGX 1,410,000) compared to non-AIP members (UGX 993,000). Also, the household per capita cassava cash income is also significantly higher among the AIP participants (UGX 2,544,672) compared to non-AIP participants (UGX 260,758).

With regard to individual contribution of stems and roots to cassava cash income, the latter was disaggregated into tuber and stem incomes for the pooled sample and for AIP and non-AIP participants (See appendix A3.1). While stem income is derived from stem seed sales only, tuber income is derived from sales of fresh tubers, dried chips, flour, cooked cassava, cassava cake, cassava bread and cassava beverage. Disaggregated results indicate that tuber income is consistently higher than stem income for the pooled sample, AIP participants and non-participants. For instance, when the sample is pooled together, tuber income is higher than stem income by UGX 510,354. Disaggregating cassava cash income by AIP membership reveals that tuber incomes are higher than stem incomes by UGX 1,390,810 and UGX 211,038 for AIP participants and non-AIP participants respectively. This is expected because while stems are only used for only one purpose (seed) and do not require any form of processing or value addition other than packaging; roots can be sold as fresh roots, and can also be processed through value addition into several products as shown above such that their value increases with the level of value addition.

In addition, Table 3.1 above presents statistics on food security indicators. AIP members are more food secure compared to non-AIP members. Indeed, AIP members reported more meals per day. In the same vein, less of AIP members reported that that they were food deprived in 2015, and also reported fewer months when food insecure. On the other hand the non-AIP members had fewer meals per day, majority reported that they were food deprived in 2015 and for more months.

Households that were AIP members are wealthier compared to non-AIP members in terms of total asset value, land holdings, and Tropical livestock unit. This is further confirmed by all the three FGT poverty measures which show that non-AIP members are worse off in all poverty measures compared to AIP members. Also, there were more AIP members who reported that they have TVs, Radios, and Mobile Phone compared to non-AIP members. There were 18% of AIP members with TVs in 2015 compared to 9% of non-AIP members.

Table 3.1 also presents information on the means of transport owned. The statistics show that 30% of AIP members owned a motorcycle compared to 15% of non-AIP members who had a motorcycle. Also, 6% of AIP members had vehicles, a number that is significantly higher than that of non-AIP members (2%) who owned vehicles.

Table 3.1 presents descriptive findings that compare farmer perceptions about the use of improved seed varieties and the seed acquisition channels across AIP and non-AIP participants. The statistics show that more AIP members are satisfied with the use of improved varieties, and seed inspection services. A smaller percentage of AIP members (42%) trust farmer seed channels compared to 59% of non-AIP members who trust famer channels. On the other hand, AIP members trust formal channels such as government and certified CSE channels compared to non-AIP members. For instance, 68% of AIP members trust government channels and 39% trust certified CSE channels. These statistics are significantly higher than 39% and 25% of non-AIP members who trust in government and certified CSE channels respectively.

There are also significant differences between AIP and non-AIP members regarding access to credit and extension. More AIP members were trained in the use of improved varieties and agronomical practices. For instance, in 2015, 60% of the

AIP members accessed credit compared to 40% of non-AIP members who received credit. On training, 42% of AIP members got training in agronomy significantly higher than 6% of non-AIP members who received the same training. Also, 72% of AIP members received extension in 2015 compared to 14% of non-AIP members who received extension.

There are differences in household demographic characteristics between AIP and non-AIP members. For instance, AIP-members household heads have higher schooling years, have larger family sizes, and are headed by older household heads. In addition, there are more female headed households among the non-AIP members than AIP members, and the difference is significant at 1%. These findings suggest self-selection in AIP membership depending on wealth, education, and family composition because the household characteristics favor AIP-member families. Lastly, there are more households where the husband is the sole decision maker among the AIP members than non-AIP members.

3.10 Determinants of farmer participation in agricultural innovation platforms

3.10.1 Introduction

This sub-section examines the determinants of household participation in Agricultural Innovation System (AIS) initiatives through membership of Agricultural Innovation Platforms (AIP). While the descriptive statistics suggest that the households that participated in AIS initiatives were more educated and wealthier, had more communication and transport facilities, had higher group membership levels, and had received more extension services compared to those who didn't participate in AIS initiatives, it was not possible to derive interpretations without controlling for other contemporaneous factors. This section controls for many other factors in a probit estimation so as to arrive at more robust conclusions about the causal determinants of household participation in AIS initiatives.

3.10.1.1 Empirical strategy of the probit model

In this study, the dependent variable takes on the value of 1 if a household participated in any of the AIS initiatives (CRCoE and or CSE) described in earlier sections and zero if otherwise. Estimating the qualitative response of a dummy dependent variable, according to Gujarati (2004), is done through three empirical strategies: linear probability model (LPM), logit model; and probit model. The linear probability model (LPM) is a typical regression model which would require a continuous dependent variable, but in the case of this study, the dependent variable is a dummy variable. Therefore, the conditional expectation of the dependent variable, given independent variables is interpreted as a conditional probability (i.e. the coefficient on the independent variable shows the magnitude of the likelihood effect on the binary dependent variable).

According to Wooldridge (2009) and Gujarati (2004), the linear probability model has considerable limitations which include: non-normality of the error term, the probabilities can be less than zero or greater than one, and the partial effect of any independent variable is constant. To circumvent these limitations, logit and probit models are suggested as limited dependent dummy variable estimation models. While the logit model is based on a logistic cumulative distribution function, the probit model follows a normal cumulative distribution function. Both the logit and probit probability models are able to circumvent the limitations of the linear probability model in the following ways: (a) as the independent variable X_i increases, the probability of participation (i.e., P_i = (Y=1|X) increases, but only in the 0-1 interval; and (b) the relationship between P_i and X_i is nonlinear. Therefore, the probability approaches zero as X_i approaches negative infinity and the probability approaches one as X_i approaches positive infinity. Thus, because the logit distribution has bigger tails than the probit distribution, the conditional probability approaches zero or one at a slower rate in the logit than in the probit model (Gujarati, 2004).

Accordingly, the probit model was adopted to analyze households' AIS participation decision in as far as it is an appropriate econometric model for the binary outcome dependent variable whose error term is assumed to be normally distributed unlike in the logit model (Wooldridge, 2009). For this reason, the probit model is preferred to the logit model by most economists. In specifying the model, this study followed the works of Lopes (2010), Zavale et al. (2005), Uaiene et al. (2009), and Mwesigye and Matsumoto (2016).

The probit model estimates the effects of X_i on the response probability, P_i= (Y=1|X). The model assumes that households make decisions based on a utility maximization objective. The model assumes that the households' decision on whether or not to participate in AIS initiatives depends on unobservable utility index (or a latent variable) that is determined by household specific attributes X (e.g. wealth status, socio-demographic factors like gender, age, and education; access to extension services, group membership, decision-making, etc.). The probit model of AIS participation is derived from an underlying latent variable model, which is expressed as:

$$Y_i^* = \beta_0 + \beta_{ij}X_{ij} + e_i \qquad \text{(E3.1)}$$

Where Y_i^* is an underlying index reflecting the difference between the utility of participating and not participating in AIS initiatives; β_0 is the intercept; β_{ij} is a vector of parameters to be estimated; X_{ij} represents independent variables which explain participation in AIS initiatives, and e_i is the standard normally distributed error term that is independent of X_j and is symmetrically distributed about zero. From the latent variable model (E3.1) and the assumptions given, the household's participation in AIS initiatives is derived as:

$$P(Y_i^* = 1|x) = F\big(\beta_0 + \beta_{ij}\beta_{ij}\big) \qquad \text{(E3.2)}$$

Where F is the function that ensures the likelihood of participating in AIS initiatives is strictly between zero and one. Thus, a household participates in AIS initiatives if $Y_i^* > 0$, and otherwise if $Y_i^* \leq 0$. Taking a normal distribution function, the model to estimate the probability of observing a household participating in the AIS initiative can be explicitly stated as:

$$P(Y_i^* = 1|x) = F(\beta X) = \int_{-\infty}^{\beta X} \frac{1}{\sqrt{2\pi}} exp(-Z^2/2)dz \qquad \text{(E3.3)}$$

Where P is the probability that the ith household participated in AIS initiatives and 0 otherwise; X is the K by 1 vector of the independent variables; Z is the standard normal variable, i.e., $Z \sim N(0, \sigma^2)$; and β is the K by 1 vector of the coefficients to be estimated.

The essence of regression analysis is to estimate the marginal effect of an independent variable on the dependent variable while controlling for the influence of other independent variables (Gujarat, 2004). Unlike in linear regressions where parameter estimates can be interpreted as marginal effects, we cannot do the same with non-linear regressions or binary dependent variable regressions like probit or logit unless we calculate the derivative of the outcome probability with respect to the independent variable.

In most applications of binary dependent variable regression models like probit, Gujarat (2004) and Wooldridge (2009) contend that the main aim is to explain the effects of the X_j on the probability regression $P_i(y = 1|X)$. The latent variable formulation (E3.1) indicates that the AIS participation model is primarily interested in the effect of each X_i (e.g. households receiving extension training) on Y_i^* (whether or not to participate in AIS initiatives). Since this study's set of independent variables includes both discrete (binary) e.g. 1 if received extension and 0 if otherwise and continuous variables e.g. number of education years; Wooldridge (2009) explains that for the discrete or binary independent variables, partial effect from changing X_i from zero to one, holding other variables constant is given by:

$$f(\beta_0 + \beta_1 + \beta_2 X_2 + \cdots + \beta_k X_k) - f(\beta_0 + \beta_2 X_2 + \cdots + \beta_k X_k), \quad \text{(E3.4)}$$

while for the continuous variables is given by $f(\beta_0 + \beta_X)\beta_j$. (E3.5)

3.10.1.2 Data used in the study

This study used cross-sectional household survey data collected from 609 cassava farming households of Eastern, Northern and Mid-Western Uganda. Using a pre-tested structured questionnaire (Appendix A5.5), data was collected on a set of variables, inter alia, as presented in the next sub-section.

3.10.1.3 Description of variables used in the probit model

Dependent variable

In this study, the dependent variables are 1 and 0 dummy variables which indicate whether or not a household participated in AIS initiatives respectively. In this regard, the probability of a households' participation in AIS initiatives is explained and estimated by: the sign, the statistical significance, and the magnitude of the parameter of estimates in the probit AIS participation model.

Independent variables

The household's decision whether or not to participate in AIS initiatives is hypothesized to be associated with several independent variables. Accordingly, this study classifies independent variables into seven (7) categories: institutional factors;

socio-demographics; wealth status, communication enablers, transport means, decision-making and regional dynamics.

***Institutional factors*:** Access to extension services in the pre-intervention year (2010) and household membership to a farmer group or association are dummy variables that take on the value of 1 if the household received extension services in 2010 and was a member of a farmer group in 2015; and 0 if otherwise. According to literature, both access to extension services and group membership expose households to more information and learning opportunities and thereby increasing their chances of learning about the importance of agricultural innovation platforms. In deciding whether or not to participate in AIS initiatives, households need information on the exact benefits accruable from joining agricultural innovation platforms (AIPs). Such information can be attained through agricultural extension services and group memberships. For these reasons, this study included these two institutional variables to assess whether access to extension services and group membership are associated with the household's decision to participate in the AIS initiatives.

***Socio demographic characteristics*:** Under this category, average education years of a household, age and gender of household head, and the dependence ratio were included. Household average education years is a continuous variable that captures the total number of formal education years of all household members divided by the household size. Education level has implications on decision-making with regard to participation in AIS initiatives. Age of household head is also a continuous variable that may be associated with participation in AIS initiatives because young and old farmers respond differently to innovations. Household head's gender is included as a dummy categorical variable that takes on the value of 1 if household head is female and 0 if male. The household head gender variable is included to control for and explain the cultural institutional limitations imposed on women with regard to free association and property ownership. This study further includes dependence ratio as a continuous variable that shows the number of active workers and dependents in a particular household. Dependence ratio has implications on the resources available for the wellbeing of a household and as such is included to assess its influence on the decision to participate in AIS initiatives.

***Wealth status variables*:** This set of explanatory variables include number and value of livestock animals measured through Tropical Livestock Units (TLUs[16]) owned by a household and the per capita total asset value (UGX) of a household. Availability of resources may determine one's ability to participate in AIS initiatives.

Communication enablers: Communication enablers are included as household ownership of television and radio sets. These two have a lot of bearing on information access which in turn may influence a household's decision to participate in AIS initiatives.

Transport means: Since AIP interactive sessions are commonly held in central places (e.g. village, parish and sub-county administrative centers), transport facilities may influence a household's decision to participate in AIS initiatives. Thus, ownership of bicycle and vehicle were included in the probit estimation.

***Decision-making*:** Household decision-making dynamics may influence participation in AIS initiatives in as far as joint decision-making yields better outcomes than single decision-making especially between spouses. It should further be stated that gendered decision-making affects both production and non-production outcomes.

Regional dynamics: captured as dummy variables taking on the value of 1 if a household is domiciled in the Mid-western or Northern regions and 0 for eastern region, regional dynamics are included to assess the effect of geographical location on decision to participate in AIS initiatives. Population-wise, the Eastern region leads followed by the Western region and lastly the Northern region. In terms of cassava production, Uganda Bureau of Statistics reports that the Eastern region leads followed by the Northern region and lastly the Western region (UBOS, 2015).

[16] Tropical Livestock Units are livestock numbers converted to a common unit. Conversion factors are: cattle = 0.7, sheep = 0.1, goats = 0.1, pigs = 0.2, chicken = 0.01 (Harvest Choice, 2011). TLU conversion factors constitute a compromise between different common practices.

3.11 Results and discussion on the determinants of AIS participation

Table 3.2: Determinants of household participation in AIS Initiatives

The dependent variable takes 1 if household participated in AIS and 0 otherwise (Marginal effects are reported)		
	(1 –without regional controls)	(2- with regional controls)
Institutional factors		
1 if received extension in 2010	0.486*** (9.218)	0.489*** (9.224)
HH group membership	0.174*** (3.742)	0.175*** (3.718)
Socio-demographics		
HH Average Education Years	0.0177 (1.630)	0.0180* (1.649)
Age of HH head	-0.00124 (-0.822)	-0.00116 (-0.765)
1 if female head is female	-0.0916 (-1.500)	-0.0898 (-1.460)
Dependence ratio	-0.0641** (-2.385)	-0.0619** (-2.290)
Wealth status		
TLU 2010	0.00585* (1.649)	0.00554 (1.580)
PCTotAssetValue000 (UGX)	-1.28e-06 (-0.839)	-1.15e-06 (-0.744)
Communication enablers		
1 if Had TV in 2010	-0.0119 (-0.170)	-0.0135 (-0.192)
1 if Had Radio in 2010	-0.0376 (-0.889)	-0.0392 (-0.924)
Transport means		
1 if Had Bicycle in 2010	0.0412 (0.910)	0.0402 (0.877)
1 if Had Vehicle in 2010	-0.00872 (-0.0895)	-0.0115 (-0.119)
Decision-making		
1 if Husband Decides	-0.0413 (-0.640)	-0.0411 (-0.636)
1 if Husb & Wife Decide	-0.0714 (-1.088)	-0.0738 (-1.121)
1 if All Decide	-0.101 (-0.961)	-0.0954 (-0.885)
1 if Others Decide	-0.0529 (-0.539)	-0.0536 (-0.549)
Regional dynamics		
1 if Mid-Western Region		0.00298 (0.0613)
1 if Northern Region		0.0301 (0.658)
Observations	*533*	*533*

z-statistics in parentheses; * p<0.1 is significance at 10%; ** p<0.05 is significance at 5%; and *** p<0.01 is significance at 1%

Table 3.2 presents the determinants of participation in AIS initiatives through AIP membership. In agreement with Mapila et al (2012), the results indicate that extension service provision is positively and significantly associated with AIP membership. Indeed, farmers that had received extension services in 2010 were 48-49% more likely to join AIPs than their counterparts that had not received any extension service in 2010. Farmers started joining AIPs in 2011 after the 2010 extension service provision, suggesting that the observed relationship can be interpreted as causation. According to Magrini and Vigani (2016), the use of pre-intervention information (year 2010 responses) mitigates reverse causality challenges.

These results might be due to the fact that extension agents train farmers about best farming practices, and the role of farmer group membership which might motivate farmers to join AIPs (Wellard et al., 2013). It might also be a reason as to why the households that belong to farmer groups are more likely to also be AIP members. Farmer groups enhance social cohesion, and promote group activities such as savings and informal group loans. This might motivate farmers to join other related farmer interactive associations like AIPs.

The results also show that households with more educated members are more likely to be AIP members than their counterparts that are less educated. This may be because educated people appreciate the importance of information and would be willing to join initiatives that enhance their farming knowledge.

The results further reveal that dependence ratio is negatively and significantly (1% level) associated with AIS participation through AIP membership. Households with more dependents are less likely to join AIPs and this could be explained by the incapacitation and inability associated with having many dependents in a household. High dependence ratios in households create resource constraints that may prevent the household from even affording mobility costs required for participation in AIPs. Indeed, during FGDs, farmers reported that they lack the time to attend AIP sessions since they have to cater for their many young ones at home. This includes female headed households with limited time availability.

Wealth status measured by the Tropical Livestock Units (TLUs) owned in 2010 is positively but weakly (10% level) associated with AIP membership. In agreement with the explanation on dependence ratio, wealthier households have the means and capacity to incur costs incurred in AIS participation. For example, households need to incur transportation costs for AIP meetings and interaction sessions which are in most times held at administrative centers like sub-county, parish or village headquarters. Sociologically too, it is important to mention that households with wealth may have wider social networks which enable them to associate and interact freely with other people especially in institutional formations like AIPs.

Contrastingly, no association was found between household assets, family decision-making dynamics, household head age and gender; possession of communication and transportation facilities as well as regional dynamics with AIP membership. This finding contradicts with farmer reports during FGDs where they stated that lack of transport means inhibits their participation in AIPs.

3.12 Impact of participation in cassava AIPs using PSM

3.12.1 Empirical strategy of Propensity Score Matching

The fundamental evaluation (impact assessment) problem results from the simple fact that one cannot observe the counterfactual corresponding to any technological or policy change being considered. In other words, if a technological or policy change does occur, one cannot observe what would have happened to the various outcomes in the absence of the change; and if it does not occur, then one cannot observe what would have happened if the change did actually take place (Asfaw, 2010). This inability to observe the counterfactual in any impact assessment study is the reason why impact assessment is viewed from a statistical perspective as a problem of missing data (the counterfactual). In fact, the statistical procedures used to derive unbiased estimates of impact outcomes are in essence designed to create an environment or a set of data that reflects as closely as possible the missing counterfactual.

Since this impact evaluation was carried out after the AIS participation had started, ex-post changes in outcome variables were used as a measure of impact. The problem with this is that there are many observable and non-observable time variant characteristics which may alter outcome variables for the participants (Rubin, 1974). It therefore becomes difficult to attribute changes in the outcome variables to a specific intervention, since comparison of the before and after changes in the outcome variable can lead to either over- or under-estimation of the intervention's impacts (Mapila et al 2012).

According to the works of Martin (2009), Wellard et al. (2013) and Mapila et al. (2012) the attribution problem is circumvented by using data on outcome variables from a control group of non-intervention participants. To be valid, the control group has to have observed characteristics identical to those of the study participants, with the only difference being participating in the intervention programme. The observed characteristics can be the households' socioeconomic characteristics and farming systems. However, according to Ravallion, (2003), the availability of data from non-participants is, in itself, not sufficient for attributing differences in outcome variables to an intervention, as changes in the outcome variables for participants may also arise from 'selection bias' in that participants may have been purposively selected.

To circumvent the selection bias, non-participants who are used for comparison purposes must, in addition to having identical observable characteristics, be those who would have had an equal chance of being selected to participate in the intervention. Thus, according to Baker (2000), Asfaw (2010), Kuntashula and Mungatana (2013) and Mapila et al. (2012), PSM is the only known approach to solve the problem of establishing a valid control group in the absence of randomization, which equalizes the probability of participating in an intervention and removes selection bias.

Propensity Score Matching (PSM) is one of the most commonly used quasi-experimental methods to address the evaluation problem (Nkonya et al., 1997; Mendola, 2007; Akinlade et al., 2011; King and Nielsen, 2016. The aim of PSM is to find the comparison group (counterfactual) from a sample of non-participants that is closest to the sample of participants based on observable characteristics so that by comparing the two (participants and this counterfactual of non-participants), the causal impact of the innovation on the participants can be identified. Though the participants and comparison groups may differ in unobservable characteristics, if they are matched in terms of observable characteristics, Baker (2000) argues that selection on unobservable characteristics is empirically less important in accounting for evaluation bias. It therefore remains, however, a weakness of the PSM method, that it does not correct bias caused by unobservable covariates (King and Nielsen, 2016).

Also in a situation where the same questionnaire is administered to both groups (so that outcomes and personal characteristics are measured in the same way for both groups) and the participants and controls are placed in a common economic environment (such as was the case in this study), matching substantially reduces bias (Heckman et al., 2001). The main steps involved in the application of statistical matching to impact evaluation are: estimating the propensity scores of the

AIS participants and non-participants using probit or logistic regression analysis, matching the propensity scores between the participants and non-participants using nearest neighbor, kernel, and radius options, assessing the quality of the matches and estimating the impact.

While applying PSM in this study, the AIS participating group was denoted H_I=1 and the non-AIS group H_i= 0. According to Mapila et al (2012), participating households are matched to non-participating households on the basis of the probability that the non-participants would have participated. This probability is called the propensity score. It is given by:

$$P(X_i) = \mathrm{Pr}ob(H_i = 1 | X_i)(0 < P(X_i) < 1) \quad \text{(E3.6)}$$

where X_i is a vector of pre-participating control variables.

As suggested by Mapila et al. (2012), the pre-participating control variables are those which are based on knowledge of the intervention under evaluation and on the social, economic and institutional factors that might influence their participating in the intervention. The vector can also include the pre-intervention values of the outcome variables. Propensity score matching cannot reproduce the results of experimental randomization designs if the variables that influence participating in the intervention are not properly defined (Asfaw, 2010; Mapila et al. 2012).

In this study, the two PSM assumptions that are observed include: (a) The Conditional Independence Assumption (CIA) which postulates that outcomes are independent of participating given the variables that determine participation (X_i). Also, that outcomes are further independent of participation given $P(X_i)$ since they would be in a randomized experiment; (b) the H_i's are independent over all *I*'s. It is worth noting that, just as randomization would do, PSM equalizes the probability of participating across the population. The only difference is that PSM achieves this based on conditional probabilities which are conditional on the variables determining participation (X_i).

Propensity Scores for each household in the sample were estimated using logit regression modeling following the works of Madola et al. (2011) and Mapila et al. (2012). Using the estimated propensity scores, matched pairs were established on the basis of how closely the participating and non-participating samples' probability of participating in the AIS intervention matched. Unmatched non-participating households were dropped from the analysis in order to remove bias and increase robustness (Ravallion, 2003). Using the Nearest Neighbor (NN) matching technique, the best matched or nearest neighbor to the j^{th} participating household is the counterfactual household that minimizes $[P(X) – P(X_j)]^2$ over all j's in the set of counterfactual households.

Following Ravallion, (2003), a typical PSM estimator of the average impact of any intervention takes the following form;

$$\Delta\overline{Y} = \sum_{j=1}^{T}\omega_j\left(Y_{ji} - \sum_{i=1}^{C}W_{ij}Y_{ij0}\right) \qquad \text{(E3.7)}$$

where:

Y_{ji} = is the post intervention outcome variable for the j^{th} household in the participating group

Y_{ij0} = is the outcome indicator of the i^{th} counterfactual household matched to the j^{th} participating household

T = total number of participating households

C= total number of counterfactual households sampled

W_{ij}'s = are the weights applied in calculating the average outcomes of the matched counterfactual households

ω_j = are the sampling weights used to construct the mean impact estimator.

To circumvent contamination problems of endogeneity of access to the cassava AIS participation, the regression model for cassava AIS participation estimated to generate Propensity Scores was run for only the matched comparison group. The estimator then takes on the following form:

$$\Delta\overline{Y} = \sum_{j=1}^{T}\omega_j\left[\left(Y_{ij} - X_j\beta_0\right) - \sum_{i=1}^{C}W_{ij}\left(Y_{ij} - X_i\beta_0\right)\right] \qquad \text{(E3.8)}$$

Where:

$\hat{\beta}_0$= the Ordinary Least Squares (OLS) estimate for the counterfactual matched group.

Since PSM does not require a parametric model linking AIS participants to outcomes, the impact estimator is approximated without any arbitrary assumptions about functional forms and error distributions (Ravallion, 2003). Thus this non-parametric nature of PSM makes it superior to non-experimental regression-based approaches. In this study, a logit regression model of participating in the cassava AIS initiative was estimated in order to determine the probability of a household participating in the AIS initiative. Participation was modeled as a dichotomous dependent variable determined by a set of exogenous variables that determined participation in the AIS cassava initiative. These exogenous variables included: a) household characteristics (age, gender, education level of household head and family size; b) wealth, information, credit and extension access, social networks and training participation (credit access, extension services, social networks, livestock ownership, information access, land access and asset value; c) community and access related variable (access to tarmac roads); and d) regional location variable (region).

The model takes on the following functional form

$$Part = f(Age, Gender, Educ, Fsize, credit, extn, networks, TLU, TV, land, Assets, Tarmac, Region) \quad \text{(E3.9)}$$

Where:

Part = Participating in cassava AIS Initiative (1= Participant, 0= Non-participant)

Age= Age of the household head

Gender= Gender of household head (1=female)

Educ= Education level of household head

Fsize= Family size

Credit= Access to credit (1= accessed credit)

Extension = Receipt of extension services (1=received extension services)

Networks = social networks measured by number of people reliable upon

TLU= Livestock ownership measured by Tropical Livestock Units

TV= Information access through ownership of Television
Land= Land access measured by total land in acres operated by the household
Assets= Household Asset value in 000' UGX
Tarmac= Community access measured by presence of tarmac road in the community
Region = Location variable measured by regional dummies
As specified by Gujarati (2004), logistic regression modeling has a major assumption that the data has a binomial distribution taking on the following form:

$$Y_i \sim B(n_i, p_i) \; for \; i = 1 \ldots\ldots n \qquad \text{(E3.10)}$$

Where:

Y_i = Participating in the AIS intervention

p_i = Unknown probability of participating

n_i = Observable outcomes of participating for each household

The logistic regression model assumes that there is a set of explanatory variables that can inform the final probability of participating (Gujarati, 1992). Due to this assumption, the explanatory variables can be taken to be in a κ vectorX_i. If we model the natural log of the odds of the unknown binomial probability p_i as a linear function of the X_i's, the following is obtained:

$$\ln\left(\frac{p_i}{1 - p_i}\right) = B_0 + B_1 x_i + \mu; i = 1 \ldots n \qquad \text{(E3.11)}$$

where: B_0 and B_1 are the intercept and the unknown parameters respectively.

3.12.2 Summary of PSM analysis and computational approaches

In summary, using propensity scores for AIS participation generated through logit regression modeling, households in the AIS participating group were matched on the basis of the proximity of their propensity scores of participation to those of households in the control group. All other households whose propensity scores for participation were different from the range of scores for the participating households were dropped from the analysis. Dropping all the control households whose probability of participating is different from those of the participating households makes it possible to compare differences in productivity and welfare outcomes between households that were similar and therefore comparable, and thus any differences in outcome variables between the AIS participants and non-AIS participants could be attributed to participation in the AIS initiative (Ravallion, 2003; Mapila et al 2012).

The conditional independence assumption (CIA) under PSM is premised on the fact that once we control for a vector of observable variables X, then the decision to participate in the AIS initiative is random. To ensure that the CIA is observed, the balancing property is tested following the standardized bias approach proposed by Rosenbaum and Rubin (1974) based on checking the differences in covariates between adopters and non-adopters before and after the procedure. Following Magrini and Vigani (2016), the study also re-estimated the propensity score on the matched sample to verify if the pseudo-R^2 after the matching is fairly low and finally a likelihood ratio test on the joint significance of all regressors was performed following Sianesi (2004). The Pseudo R^2 indicates the goodness of fit of the logit regression before (over the full sample) and after (only on the matched sample) the matching procedure. The p-values report the joint significance of the covariates in the logit regression before and after matching.

The sensitivity of the PSM estimates to a hidden bias was verified by testing for the presence of unobserved covariates that simultaneously affect household participation in AIS initiatives and the productivity and welfare outcomes. This was achieved by applying the Rosenbaum bounds test (Rosenbaum, 2002) which measures the amount of unobserved heterogeneity to be introduced in the model to challenge its results following the works of Magrini and Vigani (2016). Finally, the robustness of the PSM results is tested through sensitivity analysis by estimating the Average Treatment Effect on the Treated (ATT) using the Nearest Neighbor, Kernel and Radius matching estimation procedures. Next is a presentation of the data and description of the variables used in the PSM estimation.

3.12.3 Data and description of the variables

Outcome variable

Following Asfaw et al. (2011) and Mmbando et al. (2014), and as motivated earlier in the preceding sections, this inquiry used household cassava cash income adjusted by adult equivalents (hereinafter referred to as per capita household cassava cash income) and household consumption expenditure adjusted by adult equivalents (hereinafter referred to as per capita household consumption expenditure) as proxy indicators for household welfare. According to Magrini and Vigani (2016), per capita household total consumption expenditure has been used as a proxy for household income while many other authors have used it as a proxy for food security (e.g. Amare et al., 2012; Asfaw et al., 2012a and b; Kathage et al., 2012; Awotide et al., 2013), on the basis that at lower income the total consumption is limited and so is the expenditure dedicated to food and beverages. This makes it a powerful outcome variable in the context of this study. The consumption expenditure data was collected for the preceding year covering a period of 12 months using a standardized questionnaire developed following the LSMS-ISA standard tools making the findings of this study comparable to national and regional contextual statistics. The data was collected on purchased items and the amount spent during each spending period (week, month or year) and then aggregated to the annual level. The standard per capita consumption indicator of household welfare is based on food (household's own consumption of home produced food) plus purchased food, plus aid or gift food) and non-food expenditure adjusted by adult equivalent units (Runge-Metzger, 1988; Asmah, 2011).Cassava productivity was measured using cassava stem yield (bags/acre) and cassava root yield (Kgs/acre).

Treatment or dependent variable

The dependent variable in the PSM estimation was the binary response dummy equaling to 1 if the household belonged to any Agricultural Innovation Platform (AIP) and equal to 0 if otherwise.

Explanatory or independent variables

Following Magrini and Vigani (2016), the choice of the explanatory variables is driven by both theoretical and empirical considerations. In order to fulfil the CIA in PSM estimation, Caliendo and Kopeinig (2008) observe that the matching procedure imposes the selection of covariates, which influence the AIS participation decision but also the outcome variables (productivity and welfare indicators). It is further argued that the covariates must not be affected by participation in the innovation or the anticipation of it. This leads us to select only covariates which are not affected by time or are clearly exogenous to the treatment.

Accordingly, the study used household characteristics which included household head age and its square, household head gender, education level and family size. Wealth effect and training participation were captured using total value of household assets, household land endowments and livestock ownership adjusted to Tropical Livestock Units (TLUs). Alen et al. (2008) and Mmbando et al. (2014) posit that these variables are critical in production that enables households to produce surplus for the market. Magrini and Vigani, (2016) explain that the exogeneity is ensured by the fact that each household owns a very limited amount of land, mainly cultivated for subsistence purposes, and they are cash and credit constrained, hence there are very limited possibilities for them to allocate more land to cassava cultivation, despite being encouraged by the higher productivity.

Following Mmbando et al. (2014), transaction costs were captured through access to an all-weather road, while shocks and vulnerabilities were captured through drought, flood, crop pests and diseases as well as high input costs. According to Asfaw et al. (2012a), access to an all-weather road affects the transaction costs in marketing agricultural inputs and the access to information. While the total number of people relied upon (social capital) is included as a proxy for institutional support; knowledge and information sources such as access to extension and credit; TV ownership, government seed sources and trainings are captured as proxies for fixed transaction costs. In literature (Asfaw et al., 2012a, Magrini and Vigani, 2016), access to extension services is considered a main channel for getting information and awareness about new technologies, but also for building human capital.

It is through extension, radio, input suppliers, other farmers and groups that farmers learn about the advantages of new technologies and make decisions to adopt them. This study therefore used a binary variable equal to 1 if the household received extension services[17] in the past 12 months, and 0 otherwise. According to Magrini and Vigani (2016), the contact with extension agents informing farmers on

[17] This study defined receipt of extension services as any ‘contact between the farmer and the extension agent aimed at the former providing knowledge and information on various agricultural aspects including on new innovations to the former during the pre-intervention year’.

innovation clearly occurs before adoption, avoiding any reverse causality problem. A binary variable was included on credit access equal to 1 if anyone accessed credit and 0 otherwise because credit availability is considered in the literature (Feder et al., 1985, Magrini and Vigani, 2016) as one of the necessities for participation in an agricultural innovation and lack of credit can significantly limit the participation also in the case of low fixed costs. In this regard, access to credit is clearly exogenous. However, albeit rarely, access to credit is not always a necessity as farmers may also finance innovations through cash especially after sale of produce or assets.

As suggested by Mmbando et al. (2014), the unobserved location-specific effects were controlled using regional dummy variables so as to capture differences in the household welfare conditions that might arise due to infrastructure, remoteness, resource endowment, production potential and farming conditions across districts and regions. These structural factors can be considered exogenous to the treatment because either they are fixed over time, beyond the household's control, or happened before the decision to participate in the innovation platform (Magrini and Vigani, 2016). Next is a presentation of the PSM empirical findings.

3.13 PSM results and discussion on the impact of participation in cassava AIS initiatives

Objective one of this study was to examine the productivity and welfare impacts of participation in Agricultural Innovation System (AIS) initiatives. Indeed, throughout the regression analysis specifications of all research objectives in this study as elaborated in the subsequent chapters, participation in formal AIS has featured as a major factor influencing technology adoption and adoption intensity as well as cassava yield and household welfare improvements.

In this specific subsection, the study estimates the productivity and welfare effects of AIS participation and the results are reported in Table 3.3 below. Various specifications of the logit model were attempted until the most complete and robust specification that satisfied the balancing tests and establishment of the common support region was obtained. In figure 3.3, the study confirms that the common support condition is met.

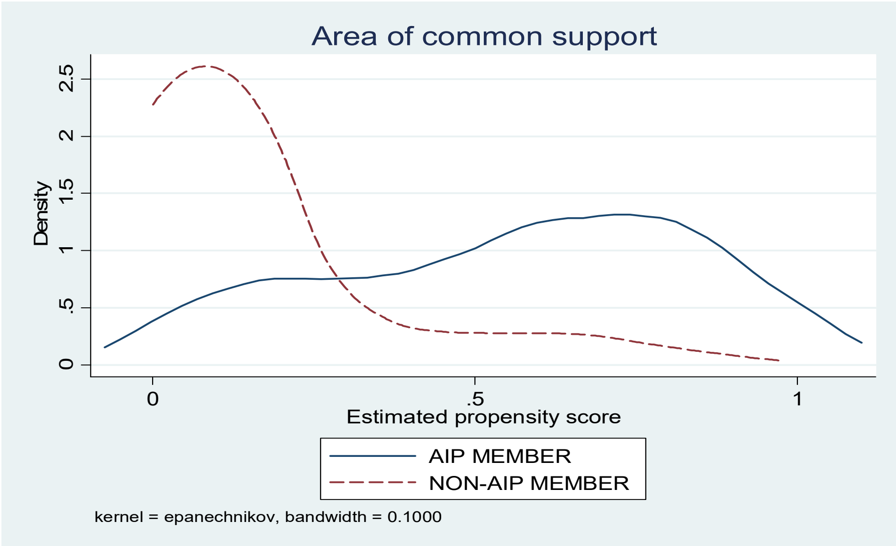

Figure 3.3: Area of common support for AIP members vs non-AIP members

Matching results are reported in Tables 3.3, 3.4, and 3.5 for the nearest neighbour, kernel and radius matching estimation techniques. The interesting general finding is that the results are robust to different matching methods. The nearest neighbour strategy used 95 households among the control units to match against 187 AIS participating households. Using the nearest neighbor matching strategy, AIS participation showed positive impact in some but not all of the productivity and welfare indicators considered.

Table 3.3: Productivity and Welfare effects of AIP Membership (NN matching)

			Outcome Variables	
	Stem Yield	*Root Yield*	*HH Cons. Expenditure Per Capita '000 UGX)*	*HH Per Cap Cassava Income ('000 UGX)*
	1	**2**	**3**	**4**
Average Treatment Effect on the Treated	30.529**	235.541	248.721	2011.511***
t-statistic	(2.593)	(0.554)	(1.449)	(4.086)
Number of farmers with AIP membership (Treated)	187	187	187	187
Number of farmers without AIP membership (Control)	95	79	95	95

Standard errors are computed using bootstrapping. t-statistics in parentheses; * p<0.1 is significance at 10%; , ** p<0.05 is significance at 5%; and *** p<0.01 is significance at 1%

In agreement with previous findings (Mapila et al., 2012), the results indicate that AIS participation had a positive and significant impact on productivity and welfare outcomes (cassava stem yield and household per capita cassava cash income). Indeed, results in Table 3.3 show that AIS participation increases stem yield by 30 bags per acre, significant at five percent, while the household per capita cassava income is 2,011,000 UGX higher for AIS participants than their non-AIS participant counterparts. Participation in AIS initiatives did not have a significant impact on root yield and household per capita consumption expenditure. These results improve when the study uses more robust matching strategies (Kernel and radius) as shown below.

Table 3.4: Productivity and Welfare effects of AIP Membership (Kernel Matching)

	Outcome Variables			
	Stem Yield	*Root Yield*	*HH Cons. Expenditure Per Capita '000 UGX)*	*HH Per Cap Cassava Income ('000 UGX)*
	1	**2**	**3**	**4**
Average Treatment Effect on the Treated	26.911**	254.186	358.290**	1988.910***
t-statistic	(2.125)	(0.887)	(2.179)	(3.304)
Number of farmers with AIP membership (Treated)	187	187	187	187
Number of farmers without AIP membership (Control)	444	444	444	444

Standard errors are computed using bootstrapping. t-statistics in parentheses; * p<0.1 is significance at 10%; , ** p<0.05 is significance at 5%; and *** p<0.01 is significance at 1%

While the Nearest Neighbour (NN) matching algorithm ensures only a few observations from the comparison group are used to construct the counterfactual outcome of a treated individual, Kernel matching (KM) is a non-parametric matching estimator that uses weighted averages of all individuals in the control group to construct the counterfactual outcome. For this reason, Caliendo & Kopeinig, (2005) conclude that KM is associated with lower variance because more information is used. No wonder, using KM, the results indicate strong positive statistical significant impact of AIS participation on all except one outcome under study.

The kernel matching strategy used more control units (444) to match against the 187 AIS participating households. Unlike the nearest neighbour approach, the kernel matching strategy results showed that AIS participation had positive and significant impacts on all the productivity (except root yield) and all welfare variables considered. Participating in AIS initiatives had a positive impact on cassava yield, per capita household consumption expenditure and per capita household cassava cash income.

Table 3.5: Productivity and Welfare effects of AIP Membership (radius Matching)

	Outcome Variables			
	Stem Yield (Kg/acre)	*Root Yield (Kg/ acre)*	*HH Cons. Expenditure Per Capita ('000 UGX)*	*HH Per Cap Cassava Income ('000 UGX)*
	1	**2**	**3**	**4**
Average Treatment Effect on the Treated	12.388**	NC	207.261**	2229.380***
t-statistic	(2.865)	NC	(2.732)	(4.029)
Number of farmers with AIP membership (Treated)	157	NC	158	158
Number of farmers without AIP membership (Control)	427	NC	428	428

Standard errors are computed using bootstrapping. t-statistics in parentheses; * p<0.1 is significance at 10%; , ** p<0.05 is significance at 5%; and *** p<0.01 is significance at 1%; NC= No convergence

Note: Since 1 hectare =2.47 acres, then 12.388 stem bags/acre is equal to 30.598 stem bags/ha

As was the case with KM, radius matching too uses more information (428 control units) to match against 157 treatment units and can therefore be thought to be associated with lower variance. Because of its heightened estimation power, a consistent result pattern was seen with the equally powerful KM estimation technique. Indeed, the results in table 3.5 reveal that AIS participation had positive and significant impacts on all the productivity (except root yield) and welfare variables considered. Participating in AIS initiatives had a positive impact on cassava yield, per capita household consumption expenditure and per capita household cassava income. The findings are in agreement with some of the results of Madola et al. (2011) and Mapila et al. (2012) to the effect that AIS initiatives improve household incomes and welfare.

Cassava root yield does not show statistical significance in all matching techniques possibly because of the inherent measurement challenges of cassava harvesting especially when it is done piecemeal[18] as is the case in most cassava growing communities in Uganda and elsewhere. The piece-meal harvesting makes it

[18] Piece-meal harvest means harvesting in small amounts required for the day's meal as opposed to harvesting at once

difficult to correctly remember and estimate the quantities harvested from a particular area.

Overall, the large impact of AIS participation on stem and root yields as well as on the welfare indicators of cassava cash income and consumption expenditure suggests that the development and investment plans, programme and project interventions undertaken in the past by the state and non-state actors at national and local levels for the promotion and diffusion of cassava technologies through Multi Stakeholder Innovation Platforms (MSIPs) or rather Agricultural Innovation Platforms (AIPs) were successful. To the extent that Agricultural Innovation Systems concepts such as intensification of seed inspection and certification services by the agriculture ministry and promotion of Cassava Seed Entrepreneurship were comprehensively applied in the cassava technology generation, promotion and utilization, the findings support Hypothesis 1, which states livelihood outcomes (productivity and welfare) of cassava farming households participating in AIS initiatives are higher compared to non-participating households. This is further corroborated by conversations with farmers during FGDs and KIIs in which farmers acknowledged that AIP membership carries a lot of benefits that translate to better productivity and welfare outcomes.

3.14 Conclusions and policy implications

The role of Agricultural Innovation System (AIS) initiatives is to increase stakeholder interaction and learning. Participants get to interact with one another and continuously engage in knowledge and experience sharing which ultimately benefits them. However, AIP membership is not automatic. Indeed, the descriptive statistics indicate that AIP members differ from non-AIP in many aspects such as education levels, wealth status, and extension service and training participation. On productivity and welfare indicators, the descriptive statistics show that AIP members have higher cassava stem yields and higher income and consumption per capita, than the non-AIP members.

This section also estimated the determinants of household participation in AIS initiatives through AIP membership. The results indicate that the households who received extension servicers prior to AIS initiative commencement were 49% more likely to join AIPs. In addition, highly educated households and those that belong to other groups were 1.8% and 17.5% more likely to join AIPs than their less educated counterparts and those that do not belong to other groups respectively. The use of pre-intervention information (year 2010 responses) mitigates reverse causality challenges.

The analysis of the impact of AIP membership on cassava productivity and household welfare reveal that AIP membership positively and significantly increases cassava stem yield by 12.4 bags per acre (30.63 bags/ha), per capita cassava income by UGX 2.2 million, and per capita consumption expenditure by UGX 207,000. The study also found out that AIP members were more likely to adopt productivity enhancing inputs such as the use of improved certified seed.

These findings suggest that AIP membership enhances farmers' knowledge and expertise regarding better farming practices which translates into increased productivity and welfare. Any programme that enhances AIP participation deserves support in as far as it enhances technology adoption, productivity and household welfare. One major way of enhancing AIP participation is through awareness creation using other existing programs such as extension services and farmer group memberships.

Overall, the considerable impact of AIS participation on stem and root yields as well as on the welfare indicators of cassava cash income and consumption expenditure suggests that the policies undertaken in the past by the Government of Uganda at national level for the promotion and diffusion of cassava technologies through Multi Stakeholder Innovation Platforms (MSIPs) or rather Agricultural Innovation Platforms (AIPs) were promising. To the extent that Agricultural Innovation Systems concepts such as intensification of seed inspection and certification services by the agriculture ministry and promotion of Cassava Seed Entrepreneurship were applied in the cassava technology generation, promotion and utilization leading to better livelihood outcomes, it is recommended that AIS as an IAR4D approach should be promoted sustainably with commensurate budgetary allocations through the national research and extension systems.

3.15 Contribution to knowledge and literature

To the best of my knowledge, this is the first attempt to identify and characterize cassava AIS initiatives in Uganda (CRCoE and CSE) which have both been implemented with proper AIS concepts including Multi-stakeholder Innovation Platforms herein called Agricultural Innovation Platforms (AIPs).

This is the first study to empirically examine the causal determinants of participation in the characterized AIS initiatives in Uganda. The probit model uses a rich set of variables including institutional factors, farmer perceptions, decision-making, wealth and asset variables including TLUs to explain causal determinates of participation in AIS initiatives.

None of the studies reviewed employed rigorous identification strategies except Mapila et al. (2012) who used PSM to study ERI AIS participation impacts in Malawi. Even so, Mapila et al. (2012) did not comprehensively study productivity and welfare impacts since their study stopped at incomes only. This study was done using cassava stem and root yield and per capita household consumption expenditure normalized using the more accurate Adult Equivalent Units (AEUs) and not the erroneous family size that is commonly used in most previous studies reviewed. While most previous studies conveniently chose to use per capita income as a proxy for welfare, this study used per capita household consumption expenditure which is by far a better welfare proxy or welfare outcome indicator. This is because per capita consumption expenditure is less prone to measurement error than total household income.

In both the causal determinants and impact analysis, pre-intervention (2010) data was used to mitigate reverse causality challenges. It is perceived that this is one of the first studies in recent years to empirically study cassava AIS participation impacts on productivity and welfare in Uganda. To the extent that the findings of this study are more robust and more amenable to policy advice, this study has successfully contributed to the literature on Agricultural Innovation Systems.

3.16 Study limitation and suggestions for further research

Cassava root yield did not show statistical significance in all matching techniques possibly because of the inherent measurement challenges of cassava harvesting especially when it is done piecemeal as is the case in most cassava growing communities in Uganda and elsewhere. The piece-meal harvesting makes it difficult to correctly remember and estimate the quantities harvested from a particular area. To circumvent this inherent root yield data quality challenge, it is suggested that future research should consider undertaking physical harvest of cassava from a measured-off garden portion and then approximate to the entire GPS-measured garden area. As suggested by Gourlay et al. (2017), this crop cutting which involves harvesting a small part of the field (usually 4x4 meters) and then weighing that harvest could provide a solution to yield data capture challenges in most SSA Africa socio-economic surveys.

Since this study only studied impact of AIS participation on productivity and welfare outcomes leaving out other important livelihood outcome variables, it is advisable that further research be conducted to empirically examine the impact of AIS participation on all indicators of poverty and food security using robust estimation strategies.

4 CHAPTER 4: DETERMINANTS OF CASSAVA SEED SOURCE CHOICE

4.1 Chapter summary

Following classification of cassava seed sources into certified and uncertified channels, the binary choice treatments probit model was applied to empirically examine the causal determinants of farmers' choice of cassava seed sources in Uganda. The study used a rich set of variables including institutional factors, farmer perceptions, decision-making, wealth and asset variables including TLUs to explain the determinants. The study results indicate that farmer perceptions about the use of improved certified seed and seed sources, household decision-making and input access shocks play an important role in influencing farmers choice of a given seed source. For instance, the study finds a 12% to 13% high likelihood of obtaining seed from certified sources when a husband and wife jointly make decisions. Farmers that are satisfied with seed inspection and certification services are 14-16% more likely to source seed from certified sources while limited access to improved seed was associated with a 7% less likelihood of sourcing seed from certified channels. The study thus recommends that farmer development programmes and project initiatives should deliberately encourage households to discuss and make decisions jointly as opposed to individual decision-making which mostly is flawed with limited information. In line with this, women empowerment should be treated as critical in as far as it facilitates joint decision-making in the households. Deliberate efforts aimed at changing farmer perceptions about seed access should be promoted. This can be achieved through targeted farmer training and extension services. Agricultural technology promotion should be carried out using AIS approaches so as to attain higher impact on farmers' mindsets. With the right information and guidance, farmers are able to make fully informed decisions resulting into better agricultural practices. Increasing availability and access of improved certified seed should be a targeted venture. Government should fund decentralized cassava seed multiplication centers across farming communities complemented with seed inspection and certification services. These findings provide one of the first sets of empirical evidence to support spousal roles in household decision-making (in the context of this study), use of AIS concepts in technology promotion as well as seed inspection and certification programmes in Uganda.

4.2 Background and introduction

According to the Food and Agricultural Organization of the United Nations (FAO, 2010), participating in agricultural input markets is one of the most important determinants of the way farmers utilize crop genetic resources including the crops and varieties they choose for planting. Participation in agricultural markets also has significant impacts on cassava productivity and household welfare. Input and output markets are becoming increasingly important in the agricultural sector of developing countries and hence understanding their role on the welfare improvement of smallholder farmers is fundamental for sustainable utilization and good agricultural policy making.

The World Bank (2002) recognizes that agricultural input markets are governed by a set of formal and informal rules and relationships, and these are affected by public policies and specific interventions. It is also important to recognize that one of the most pressing current notions in development is how best to govern markets to achieve economic growth and development. One major concern of economists has been improving the efficiency of markets by reducing transaction costs and providing a supportive institutional environment (Jayne et. al., 2001). As earlier noted, the role of transaction costs in a smallholder farmer's decision to participate in input and product markets has received considerable attention (Sadoulet and deJanvry, 2000; Sadoulet and deJanvry, 2003; Bellemare and Barrett, 2006). In particular, attention has focused on the identification of behavioral responses to adverse conditions characteristic of many markets in less developed countries and in policy options to reduce transaction costs and improve the functioning of markets.

Dorward et al. (2005) argue that low income economies are characterized by high transaction costs and risks, weak information flows, and a weak institutional environment such that actors with little in the way of financial and social resources or political leverage face high costs which inhibit both market development and access to existing markets, in turn inhibiting economic and technological development.

The market for seeds is different from many product markets because characteristics, embodied with the seeds, are difficult to identify at the time of purchase thereby bringing into play issues of information asymmetries between the consumer (farmer) and supplier of the seed (Morris et al., 1998). The existence of such information asymmetries is a major factor in farmers' decision to exchange in the informal sector, where social relations and reputation provide some assurance of quality (Badstue et al., 2004). It has also been shown as a source of inefficiency between farmers and end-users (Lambert and Wilson, 2003; Barkely and Porter, 1996). To farmers, the decision to participate in the seed marketplace and purchase and grow a particular seed (and the embodied attributes of the crop or variety) has a significant impact upon productivity, household income, consumption and welfare. Thus, an empirical inquiry into the determinants of farmers' choice of cassava seed sources becomes paramount in terms of policy formulation.

4.3 Research objective and questions

To examine the causal determinants of the cassava seed source choice in Uganda

4.4 Research Questions

1. What are the differences in socio-economic characteristics between farmers accessing seed from certified channels and non-certified channels?
2. What are the causal factors determining the choice of the cassava seed source?

4.5 Hypothesis tested

Transaction costs and institutional factors influence farmers' choice of the cassava seed source. Transaction cost measures may include access to tarmac roads and transportation means while institutional factors may include farmer group membership, membership to AIPs, farmer networks, and access to extension and credit services. The study attempted to test the hypothesis using each of these measures.

4.6 Cassava seed access sources in Uganda

Certified cassava seed source channels include government institutions (NARO & NAADS) & certified Cassava Seed Entrepreneurs (CSEs); while uncertified channels include NGOs, fellow farmers and farmers' own saved seed. The National Agricultural Research Organization (NARO) and the National Agricultural Advisory

Services (NAADS) are both agencies of the Ministry of Agriculture which houses the National Seed Certification Services (NSCS). The certified Cassava Seed Entrepreneurs (CSEs) are a creation of the Cassava Seed System project (CSS Project) which, through the Agricultural Innovation Systems (AIS) approach, has been implemented with the involvement of the NSCS of MAAIF. Thus, NARO, NAADS and the certified CSEs all enjoy seed inspection and certification services from the NSCA of the Ministry of Agriculture. On the contrary, own saved seed, and seed from fellow farmers and NGOs are not necessarily inspected and certified owing to the limited operations of the resource constrained NSCS. In this study, seed sources are categorized based on whether they receive seed inspection and certification or not as elaborated above. Cassava seed sources that receive seed inspection and certification services are categorized as 'certified channels' while those that don't receive seed inspection and certification services are categorized as 'uncertified channels'. It is worth noting that AIS generally promote the use of improved varieties through certified seed systems, although this is dependent on the crop. Informal seed systems and non-certified seeds may continue to be preferred by farmers for some purposes (e.g. taste, drought tolerance or variety conservation and preservation). In the next section, the study presents the methodological approach used in identifying the determinants of cassava seed sources.

4.7 Empirical strategy of the probit model for seed source determinants

Since this study's outcome variable (use of certified channels or not) is a dummy dependent variable that takes on the value of 1 if a household used certified channels and 0 if a household used uncertified channels, the study may choose to apply the probit or logit model.

Consider a univariate binary model defined as:

$$P(Y_i = 1) = F(X_i B_0), i = 1,2, \dots n \quad \text{(E4.1)}$$

where: Y_i =Sequence of dependent binary random variables taking the values of 1 or 0

X_i= K vector of known constants

B_0 =K vector of unknown parameters

F = a certain known function

According to Amemiya (1981), the functional forms of F most frequently used in applications are as follows

Linear probability model: $F(X) = X$ (E4.2)

Probit model: $F(X) = X = \int_{-\infty}^{xb} \frac{1}{\sqrt{2\pi}} exp\left(\frac{-Z^2}{Z}\right) dz$ (E4.3)

Logit model: $F(X) = \Omega(\mathrm{X}) = \frac{e^{\eta i}}{1+e^{\eta i}}$ (E4.4)

From the above, the linear probability model has a defect in as far as F is not a proper distribution function because it is not constrained to lie between 0 and 1. While logit model follows logistic distribution, requires bigger samples and has standard Errors (SEs) that are not normally distributed, the probit model follows log normal distribution, is more robust to small samples and has SEs that are normally distributed. In terms of results interpretation, a positive variable coefficient means that higher values of that variable result in a higher probability of adoption while a lower value means a lower probability of adoption.

In consideration of the latent variable aspects, explaining a probit model becomes a little bit easier compared to the logistic regression. The probability of a dichotomous outcome (choice of certified channels or not) is related to a set of explanatory variables that are hypothesized to influence the outcome. Wooldridge, (2009) argues that the error term in the probit regression is assumed to be normally distributed unlike in the logit model. For this reason, the probit model is preferred to the logit model by most economists. This plus the familiarity with implementation of the '*dprobit*' routine in STATA makes us choose the probit model to study determinants of cassava seed access channels.

From probability statistics, the probit model can be derived as follows:

$Prob\ (Y = 1) = 1 - F[1 - \sum_{K=1}^{K} \beta_K b_K] = F[\sum_{K=1}^{K} \beta_K b_k] = \varphi\left[\sum_{k=1}^{k} \beta_k b_k\right]$ (E4.5)

The probability of non-adoption is then:

$Prob(Y = 0) = 1 - \varphi[\sum_{K=1}^{K} \beta_K b_k]$ (E4.6)

The household decision to use a particular cassava seed source depends on the criterion function:

$$Y^* = \gamma Z_i + U_i \qquad \text{(E4.7)}$$

where:

Y^* = Underlying index reflecting the differences between the use of certified channels and non-use

γ =Vector of parameters to be estimated

Z_i =Vector of exogenous variables which explain use of certified channels

U_i = Standard normally distributed error term

Given the household decision-making process, when ${Y^*}_i$ crosses the threshold value 0, the farmer is observed using the input in question (certified seed channels). In practice, ${Y^*}_i$ is unobservable. Its counterpart is Y_i which is defined by:
Y_i = 1 if ${Y^*}_i$> 0 (Household uses certified channels), and Y_i = 0 if otherwise (E4.8)

As earlier noted in equation (E4.1 & E4.2), in the case of normal distribution function, the model to estimate the probability of observing a farmer using certified channels can be stated as:

$$P\left(Y_i = \frac{1}{X}\right) = \varphi(X\beta) = \int_{-\alpha}^{x\beta} \frac{1}{\sqrt{2\pi}} exp\left(\frac{-z^2}{z}\right) dz \qquad \text{(E4.9)}$$

where;

P = Probability that ith household uses certified channels and 0 otherwise

X = K X 1 Vector of the explanatory variables

Z = Standard normal variable i.e$\left(Z \sim N\left(0, \delta^2\right)\right)$ and

β = K X 1 Vector of the coefficients estimated

In the case of non-dichotomous variables, the marginal probability is defined by the partial derivative of the probability that Y_i=1 with respect to that variable. The STATA routine *'dprobit'* allows us to automatically compute marginal effects as a second step after the probit regression. Thus for the jth explanatory variable, the marginal probability is defined by;

$$\frac{\partial P}{\partial X_{IJ}} = \varphi(X_i\beta)\beta_j \qquad \text{(E4.10)}$$

where;

$\varphi(.)$ = Distribution function for the standard normal random variable

β_j= Coefficient of jth explanatory variable

The probit model specification in this analysis can be presented as:

$$Y^*{}_i = X_i\beta + \varepsilon_i \qquad \text{(E4.11)}$$

$$Y^*{}_i \begin{cases} 1 \; if \; Y^*{}_i \geq 0 \\ 0 \; if \; Y^*{}_i < 0 \end{cases} \qquad \text{(E4.12)}$$

where;

Y_i = Observed dichotomous dependent variable which takes on value 1 when the ith household uses certified channels and 0 otherwise

$Y^*{}_i$= Underlying latent variable that indexes the use of certified seed channels

X_i = Row vector of values of K regressors for the ith household

β = K x 1 vector of parameters to be estimated

ε_i = Error term which is assumed to have standard normal distribution

4.8 Data used in the study

Using a pre-tested structured questionnaire (Appendix A5.5, Section 5), this study collected data on a set of variables, among others, as presented in the next sub-section.

4.8.1 Description of variables used in the probit model

Dependent variable

In this study, the dependent variables are 1 and 0 dummy variables which indicates whether or not a household sourced seed from certified channels respectively. In this regard, the probability of a household sourcing seed from certified channels is explained and estimated by: the sign, the statistical significance, and the magnitude of the parameter of estimates in the probit adoption model.

Independent variables

The household's decision whether or not to source cassava seed from certified sources is hypothesized to be associated with several independent variables. Accordingly, the study classifies the independent variables into seven (7) categories: (a) decision-making dynamics, (b) farmer perceptions, (c) institutional factors which include information, seed, extension, and credit access; vulnerabilities and shocks; group membership, participation in AIS initiatives, farmer experience and transaction cost variables; (d) household demographics and social networks; (e) land access; (f) wealth status and; (g) regional dynamics. A description of these independent variables is presented in the next section.

Decision-making: Joint decision-making involving more than one household member (especially inter-spousal decision-making) increases chances of making informed decisions which would meet objectives of all household members.

Farmer perceptions*:* In respect to trustworthiness of cassava seed source and satisfaction with seed inspection and certification services, it can be hypothesized that higher levels of trust reduce perception of risk and hence transaction costs in an exchange relationship (Woldie and Nuppenau, 2009). Trust and perception variables are expected to positively influence farmers' channel choice and are included as binary dummy variables to reflect presence or not of: (a) trust in cassava seed source and (b) satisfaction with cassava seed source inspection and certification services.

Institutional factors: As suggested in Belay et al. (2017), these include: information access, extension services access, and credit access; vulnerabilities and shocks; group membership, participation in AIS initiatives, farmer experience and transaction cost variables. With regard to household membership to an association, farmer group or Agricultural Innovation Platform (AIP), it may be hypothesized that this increases access to information critical to production and marketing decisions (Olwande and Mathenge, 2012). Since government and donor support targets farmer groups as opposed to individual farmers (usually as a way of increasing their bargaining power at time of output marketing, accessing extension advice and input procurement), membership to a farmer association increases chances of a farmer accessing seed from government and donors. This is modeled as a binary response variable with 1 if the household is a group or AIP member and 0 if otherwise.

Access to extension services: Mmbando et al. (2014) explain that agricultural extension services are expected to increase access to production and marketing information and technical skills of farmers. Extension services are also expected to facilitate smallholder linkages with input and output markets (Gebremedhin et al., 2009). Therefore, access to extension services may lead to a farmer using clean certified seed usually from government agencies than elsewhere. This is modeled as a dummy with 1 if farmer accessed extension services and 0 if otherwise. *Information access* is further increased by ownership of ICT equipment such as mobile phones, radio and TVs. Informed farmers are more likely to use certified channels because of the advantages that come with them.

Access to Credit: Modeled as a dummy with 1 if farmer accessed credit and 0 if otherwise; access to credit is understood to increase the farmers' purchasing power and therefore financial ability to access and use technological innovation.

Transaction costs variables (vehicle or motorcycle ownership and road conditions: Omamo (1998) suggests that farmers will choose closer sources to avoid transportation costs. This is especially so if they lack means of transport and if the road infrastructural conditions are poor.

With regard to farming experience, it is hypothesized that older farmers are more likely to use own saved seed or seed from neighbor (uncertified channels) because they have lost the energy and vibrancy to move extensive distances in search of certified seed (NARO, 2014). Farming experience may positively or negatively influence technology adoption in a sense that risk averse farmers may want to stick to their old proven ways of doing things as opposed to trying out new innovations.

Vulnerabilities and shocks: High input price shocks were included as dummy variables that take on the value of 1 if a household experienced the shock and 0 if otherwise. Shocks may significantly influence a household's ability to adopt a new agricultural technology especially if they are related to input access.

Household demographics and social networks: Besides its influence on decision-making, *age of household head* has implications on the availability and productivity of family labor and therefore the ease with which improved agricultural practices are adopted. Strauss et al. (1991) assert that the level of *formal education* attained is used as a proxy for the farmers' ability to acquire, process and effectively use information gathered from different sources. Thus, the household head's years of formal education is expected to increase the likelihood of accessing seed from sources that have some inspection and certification services embedded (certified channels). It can also be argued that farmers without formal education are able to innovate if provided with appropriate extension and innovation support through various means including adult education. Furthermore, both *family size* and *dependence ratio* have a direct bearing on family labor availability and therefore adoption of technological innovations (Belay et al., 2017). Bigger family sizes and higher dependence ratios may on the contrary constrain resource availability required to access innovations resulting into non adoption and therefore use of uncertified seed sources. *Social networks* too may negatively or positively influence adoption since they could result into farmers using free uncertified seed from neighbors or certified seed from innovative friendships. *Household head's gender* is included as a dummy categorical variable that takes on the value of 1 if household head is female and 0 if male. This household head gender variable is included to control for and explain the cultural institutional limitations imposed on women with regard to free association and technology adoption decision-making (Mishra et al., 2015; Forsythe, 2017).

Wealth status and land access: Farmers with relatively higher wealth will have a lower degree of risk aversion and will thus more easily adopt new innovations that are more efficient (Alemu et al., 2012).

Regional dynamics: captured as dummy variables taking on the value of 1 if a household is domiciled in the Mid-western or Northern regions and 0 for eastern region. Regional dynamics are included to assess the influence of geographical location on household's seed sourcing decision-making process.

In the next sub-section, the study presents descriptive statistics results and discussion of socio-economic and demographic characteristics followed with empirical results and discussion of adoption determinants using the probit model.

4.9 Results and discussions

4.9.1 Introduction

This sub-section aims at examining the factors that influence the choice of seed access sources. Specifically, the section presents the characteristics of the farmers who sourced seed from the certified cassava seed channels and compares these characteristics with those of the farmers who accessed seed from uncertified sources. In addition to statistics, this subsection presents the empirical results on the determinants of cassava seed access source choice.

4.9.2 Descriptive results and discussion

As a preliminary investigative procedure, descriptive statistics are presented to gain an understanding of the inherent significant socio-economic characteristics of the respondents. Table 4.1 presents a summary of the socio-economic characteristics of the respondents and variable mean comparisons between certified channels and uncertified channels.

Table 4.1: Descriptive statistics of cassava farmers

VARIABLE	CERTIFIED SEED SOURCES	SD	UNCERTIFIED SEED SOURCES	SD		t-test
Variables	**Mean (A)**		**Mean (B)**		**(A-B)**	**P-VALUE**
Productivity outcomes						
Parcel stem yield (bags/acre)	44.812	42.342	37.487	90.039	7.325	0.364
Parcel root yield (Kgs/Acre)	3040.846	2599.112	2651.404	2130.390	389.442**	0.099
n	***131***		***584***			
Welfare outcomes						
PCHHConsumption Exp'000 (UGX)	1394.883	1856.827	1033.749	767.880	361.134***	0.002
PCHHCassIncome'000 (UGX)	1739.446	4996.326	640.012	4701.326	1099.434***	0.028
Food security outcomes						
# of Meals Per Day	2.595	0.638	2.526	0.660	0.068	0.321
1 if Food deprived in 2015	0.270	0.446	0.361	0.481	-0.091**	0.069
# of months food insecure	0.613	1.222	0.792	1.362	-0.180	0.201
FGT Poverty outcomes						
Head count index (% poor)	0.548		0.714			
Poverty gap index	0.194		0.294			
Poverty severity index	0.089		0.151`			
Decision-making						
1 if husband decides	0.622	0.487	0.528	0.500	0.093**	
1 if husband and wife decide	0.225	0.420	0.228	0.420	-0.003	
1 if all decide	0.018	0.134	0.030	0.171	-0.012	

1 if others decide	0.054	0.227	0.083	0.276	-0.029	
Farmer perceptions						
1 if Satisified with local varieties	0.243	0.431	0.367	0.482	-0.124***	0.013
1 if Satisified with modern varieties	0.802	0.400	0.560	0.497	0.241***	0.000
1 if Satisified with sd inspection services	0.270	0.446	0.071	0.256	0.200***	0.000
1 if Trust Farmer cassava seed chanel	0.468	0.501	0.565	0.496	-0.096**	0.066
1 if Trust Govt cassava seed chanel	0.649	0.480	0.431	0.496	0.217***	0.000
1 if Trust Govt NGO cassava seed chanel	0.387	0.489	0.252	0.435	0.135***	0.004
1 if Trust Govt CSE cassava seed chanel	0.369	0.485	0.268	0.443	0.101***	0.033
Group membership						
1 if HH is a member of an AIP	0.495	0.502	0.200	0.400	0.296***	0.000
1 if HH head belongs to a group	0.874	0.333	0.744	0.437	0.130***	0.003
1 if Received Govt Extension in 2015	0.306	0.463	0.113	0.317	0.193***	0.000
Information access						
1 if had TV	0.225	0.420	0.087	0.282	0.139***	0.000
1 if had Radio	0.811	0.393	0.683	0.466	0.127***	0.008
1 if had mobile phone	0.865	0.343	0.817	0.387	0.048	0.226
Transaction costs						
1 if had motor-vehicle	0.072	0.260	0.026	0.160	0.046***	0.017
1 if had motorcycle	0.288	0.455	0.163	0.370	0.125***	0.002
1 if Poor transport means	0.568	0.498	0.482	0.500	0.086*	0.103
Household demographics						
# of Education school years of HH head	9.591	4.608	7.879	4.413	1.712***	0.003
Age of HH head	47.736	13.488	45.350	14.190	2.386*	0.109
Family size	6.973	2.546	7.288	3.137	-0.315	0.323
1 if HH is female	0.126	0.333	0.188	0.391	-0.061*	0.126
Seed access and farmer empowerment						
1 if Lack of improved varieties shock	0.505	0.502	0.645	0.479	-0.141***	0.006
1 if suffered high input price costs	0.667	0.474	0.681	0.466	-0.015	0.764
1 if Labor shortage shock	0.360	0.482	0.272	0.446	0.088**	0.064
1 if Lack of mechanisation shock	0.739	0.441	0.673	0.469	0.065*	0.181
Credit access and use						
1 if Accessed credit in 2015	0.468	0.501	0.456	0.499	0.013	0.807
Land access						
HH Total land operated (Acres)	20.835	72.885	19.187	180.633	1.648	0.925
1 if land is owned with title	0.144	0.353	0.125	0.331	0.019	0.587
1 if land is rented in	0.117	0.323	0.058	0.235	0.059***	0.028
1 if land was borrowed in	0.018	0.134	0.026	0.160	-0.008	0.616
Communal Land	0.009	0.095	0.020	0.141	-0.011	0.427
Wealth status						
Tropical Livestock Units (TLUs) 2015	4.298	6.020	2.634	4.162	1.664***	0.001
PCTotAssetValue2015	13800000	36500000	6721636	18000000	7078364***	0.003
n	***111***		***496***			

Source: Survey data. 0.10 (*) is significance at 10%[19]; 0.05 (**) is significance 5%; and 0.00 (***) is significance at 1%

[19] It is worth noting that 10% level of significance is quite weak

The productivity measures favour farmers that accessed seed from certified seed sources. For instance, both the stem yield (bags/acre) and cassava root yield (Kgs/acre) are significantly higher for farmers who accessed seed from certified sources. The root yield was 3,040 Kgs/acre and 2,651 Kgs/acre for farmers that used certified and uncertified cassava seed sources respectively. The difference of 389 Kgs/acre is significant at 5%. This might suggest that the seed from certified sources is of good quality and high yielding.

In addition to productivity, the welfare and food security measures favor farmers who sourced seed from the certified seed sources. The per capita household consumption expenditure and per capita household cassava cash income are significantly higher for farmers who accessed seed from certified sources than those than used uncertified sources (see Table 4.1). Also, fewer farmers (27%) of farmers who accessed seed from certified seed sources reported that they were food deprived in 2015 compared to 36% of the farmers who sourced seed from uncertified sources. The difference is weakly significant (5% level) implying that certified seed is not having a strongly significant effect on food security. The head count ratio, a poverty measure that indicated the number of people below the poverty line, shows that 71% of the farmers who sourced seed from uncertified seed sources live below the poverty line and this is significantly higher than 55% of those who sourced seed from certified sources. This suggests that the farmers who use certified seed sources are richer. These results are, however, inconclusive because at this point one cannot claim that the use of certified seed sources reduces poverty since it is also possible that it is wealthy people who can afford certified seed sources. To gain a better understanding, a deeper analysis is done in the next sub-sections.

The study also looked at the farmer perceptions and checked whether they vary by seed source choice. The statistics show that farmers who used certified seed sources (24%) are dissatisfied with local traditional varieties. On the other hand, those who sourced seed from uncertified seed channels (37%) reported that they are satisfied with the local seed varieties, and the difference between these two groups is statistically significant at 5%. Conversely, farmers who used certified seed sources are satisfied with modern seed varieties, quality of inspection services and they trust certified cassava seed sources such as Government and certified CSE channels, while those fewer farmers who used uncertified seed channels reported that they are satisfied with modern seed varieties and that they are satisfied with the inspection quality. Instead, farmers who used uncertified seed channels reported that they are satisfied with these channels. On the decision-making front, the statistics show that there is a significantly higher percentage of households where the husband is the decision maker (62%) among those who sourced seed from certified seed sources than those who used uncertified seed sources (52%).

The statistics also show that the majority of farmers who sourced seed from certified seed channels belonged to Agricultural Innovation Platforms (AIPs), farmer groups, and that they had received extension services. These same farmers had more access to information than their counterparts who access seed from uncertified seed sources. For instance, while 23% of farmers who used certified channels had TVs and 81% had radios, only 9% of those who used uncertified seed channels had TVs and 68% had radios. The difference is statistically significant at 5%. In terms of transport means, more farmers who accessed seed from certified sources reported to be having motorcycles and vehicles compared to those who used uncertified seed sources. This suggests that transport costs are relatively lower for farmers who sourced seed from certified channels, and this might indeed be the reason as to why they opted for this seed source.

On the household characteristics, households that sourced seed from certified channels are relatively more educated, and their household heads are older than those who sourced from uncertified seed channels. However, fewer households, which use certified seed channels, are female headed, and they have small family sizes compared to those that sourced from uncertified seed channels. On the wealth status, households that used certified seed channels have more livestock and assets and hence are wealthier than those who sourced seed from uncertified seed sources.

The study also looked at ease of seed access and labor cost challenges. More farmers who used uncertified seed channels reported that they had problems of lack of improved seed, high input price shocks and that they experienced high labor costs compared to those who sourced seed from certified seed channels. This might explain why these farmers opted for these kinds of seed access channels.

4.9.3 Empirical results and discussion of determinants of seed source choice

4.9.3.1 Introduction

This sub-section examines the determinants of the choice of cassava seed sources. While the statistics suggest that the farmers who sourced seed from certified channels were wealthy, had positive perceptions about the use of modern seed varieties, and had not experienced negative shocks regarding the prices of the seed and labor costs compared to those who used uncertified channels, the study could not derive interpretations without controlling for other factors. This part controls for many factors in a probit estimation so as to arrive at rigorous conclusions about the choice determinants of certified cassava seed sources.

Table 4.2: Probit model determinants of cassava seed source choice

	Dependent Variable takes 1 if the household used certified seed source and 0 if not (Marginal effects are reported	
	(1-without regional controls)	(2-with regional controls)
Decision-making variables		
1 if husband decides	0.105* (1.815)	0.0995* (1.732)
1 if husband and wife decide	0.127* (1.689)	0.117 (1.576)
1 if all decide	-0.0607 (-0.755)	-0.0496 (-0.587)
1 if others decide	0.0113 (0.137)	9.50e-05 (0.00120)
Farmer perception variables		
1 if satisfied with local varieties	0.00694 (0.211)	0.00440 (0.137)
1 if satisfied with improved varieties	0.0484 (1.498)	0.0508 (1.622)
1 if satisfied with inspection and certification services	0.162*** (3.157)	0.139*** (2.832)
1 if trust farmer channel	-0.0123 (-0.424)	-0.0103 (-0.359)
1 if trust govt channels	0.0732** (2.287)	0.0788** (2.480)
1 if trust NGO channel	-0.0212 (-0.676)	-0.0471 (-1.543)
1 if trust CSE channel	0.0147 (0.485)	0.0267 (0.860)
Institutional factors		
Seed access and farmer empowerment variables		
1 if lack improved seed	-0.0712** (-2.293)	-0.0670** (-2.113)
1 if suffered high seed cost	-0.00286 (-0.0937)	0.00360 (0.121)
1 if faced labor shortage	0.00609 (0.198)	0.00992 (0.329)
1 if lacked machines to use	0.0531* (1.874)	0.0460* (1.648)
1 if accessed credit in 2015	-0.0321 (-1.148)	-0.0315 (-1.146)
1 if AIP member	0.0493 (1.372)	0.0641* (1.755)
1 if HH belongs to a group	0.0500 (1.433)	0.0613* (1.824)
1 if got extension from govt	0.0833* (1.876)	0.0607 (1.422)

# of yrs growing local seed	-0.0112*** (-4.200)	-0.0108*** (-4.125)
Information access variables		
1 if had TV	0.147** (2.465)	0.133** (2.311)
1 if had Radio	0.0430 (1.448)	0.0234 (0.771)
1 if had mobile phone	-0.0172 (-0.443)	-0.00271 (-0.0729)
Transaction cost variables		
1 if had motor-vehicle	0.0366 (0.450)	0.0209 (0.270)
1 if had motorcycle	0.0260 (0.719)	0.00420 (0.122)
1 if suffered poor transport means	0.0409 (1.413)	0.0329 (1.158)
HH demographics and social networks		
# of yrs of school of HH head	0.00149 (0.429)	-0.000495 (-0.142)
Age of HH head	0.00179* (1.694)	0.00196* (1.855)
Family size	-0.0126** (-2.391)	-0.0114** (-2.188)
1 of HH head is female	0.0463 (0.767)	0.0380 (0.639)
# of people relied upon	-0.000125 (-0.304)	-0.000318 (-0.771)
# of people relied upon for free seed	-0.000553 (-0.771)	-0.000623 (-0.800)
Dependence ratio	-0.0108 (-0.610)	-0.00508 (-0.288)
Land access variables		
HH Total land operated (Acres)	-0.000383 (-0.764)	-0.000602 (-1.155)
Land owned with title	0.00595 (0.145)	0.0207 (0.483)
Land rented in	0.0852 (1.379)	0.122* (1.837)
Land borrowed	0.130 (1.091)	0.172 (1.350)
Communal land	-0.0355 (-0.363)	-0.0439 (-0.504)
Wealth status variables		
TLU 2015	0.00401 (0.992)	0.00553 (1.384)
Log of total asset value'000	-0.00494 (-0.348)	0.00405 (0.286)
Regional Dummies		
1 if Mid-Western Region		0.0911** (2.043)
1 if Northern Region		0.141*** (3.197)
Regional Dummies	***No***	***Yes***
Observations	546	546

z-statistics in parentheses; * p<0.1 is significance at 10%; , ** p<0.05 is significance at 5%; and *** p<0.01 is significance at 1%

Table 4.2 presents probit marginal effect results of the determinants of seed source choices. The study finds that joint decision-making (between husband and wife) on crop production and agronomic practices positively influences the choice of certified cassava seed sources. For instance, the study finds a 12% to 13% higher likelihood of obtaining seed from certified sources when a husband and wife jointly make decisions than when the husband decides alone (Table 4.2 specifications 1&2). On the other hand, when only the husband makes decisions, the likelihood of sourcing seed from certified sources is 10%, which is smaller than that of joint decision-making. Decision-making is one of the several dimensions of women's agency whose measurement needs to be improved in empirical studies.

The study also found that farmer perceptions shaped over time on seed access sources influence choices of seed access sources. Consequently, farmers that are satisfied with seed inspection and certification services are 14-16% more likely to source seed from certified sources as compared to the neutral and unsatisfied (Table 4.2, specifications 1 & 2). As earlier hypothesized, the study finds that institutional factors influence the choice of cassava seed source. For instance, results show a higher likelihood of accessing seed from certified sources if a farmer trusts government seed sources.

The results also indicate that limited access to improved seed is associated with a less likelihood of using certified channels. In Table 4.2 specifications 1&2, it is found that farmers who reported a challenge of limited access to improved seed were 7% less likely to source their seed from certified channels compared to their counterparts that weren't facing the same challenge.

While group membership and participation in an Agricultural Innovation Platform (AIP) are positively but weakly associated with accessing seed through certified channels, government extension service provision and access to information positively and strongly influence farmers' choice of cassava seed sources. Indeed, the results show that farmers that were visited by a government extension agent were 6-8% more likely to source their seed from certified channels. In addition, farmers who own TV, which is one of the major information transmission channels in Uganda, are more likely (13-15%) to source their seed from certified channels. Through information access, farmers are able to learn and appreciate the importance of using certified seed and resultantly source their seed from channels that have seed inspection and certification services embedded. For the past five years, Ugandan TV stations have consistently run a popular agricultural promotion programme called 'Seeds of Gold' and this could possibly explain the attendant result.

Also, the results show that experience in cassava growing, indicated by years a farmer has spent growing local cassava varieties, is negatively associated with choice of certified seed channels. Results indicate that a one year increase in farming experience increases the likelihood of sourcing cassava seed through uncertified channels by 1%. This might suggest that farmers get attached to traditional varieties the longer they plant them. Also, experienced farmers are sensitive to costs and can use their accumulated skills to enhance productivity of the local varieties unlike less experienced farmers who can only ensure high productivity using improved technology.

While it was hypothesized that transaction costs influence choice of cassava seed source, the study does not find a significant relationship between the status of transport means and the choice of seed sources. This might suggest that when farmers trust the sources and have positive perceptions about the use of improved certified seed, transport means do not significantly impede them from majorly accessing their seed from certified seed channels. Indeed, the results suggest that it is mainly extension service provision and information access, perceptions about seed quality and the levels of trust for the seed source that matter in the choice of seed access channel.

Upon examining whether socio-demographic factors influence the farmers' choice of seed source, the study results indicate that the bigger the family size, the less likely the household will use certified seed channels. This might be caused by the fact that big families face budgetary constraints and may therefore be less economically empowered to afford certified seed which in most cases involves incurring costs in transportation among other costs. The results also reveal that, controlling for experience in local variety cassava growing, older farmers are more likely to use certified channels. This may be attributed to the fact that older farmers have had the opportunity to study performance trends of the different options and are therefore inclined to choose certified channels which guarantee better yields.

Interestingly, the results indicate a positive and significant relationship between renting[20] land and use of certified seed. The results reveal that households that rented in land were 12% more likely to access their seed from certified seed channels. This suggests that a farmer renting in land minimizes risks associated with using seed from uncertified channels. Having spent heavily in paying land rental premiums, the farmer aims to maximize returns to investment and planting certified

[20] Land renting in this case refers to the means of access of the land on which most cassava production took place during the period studied

seed becomes one way of ensuring against losses that are usually associated with use of uncertified seed.

Intriguingly, the results reveal that social networks have negative and insignificant causal implications on the use of certified cassava seed sources. For instance, while it would be expected that farmers with many dependable people in times of need are more likely to use certified seed channels owing to the role of social capital in shielding households from vulnerabilities, the results show the contrary. Conversely, social networks, especially those that involve seed sharing, are insignificantly associated with less use of certified seed channels. Indeed, it is found that the more the number of people a farmer can rely on for free seed, the less the likelihood of sourcing seed from certified seed channels. These results, besides showing the continued importance and value of local seed networks, are not conclusive about the role of social networks in the use of certified seed sources unless the purpose[21] of the networks is considered.

Taking into account regional dynamics, households in the Mid-Western and Northern regions are 9% and 14% more likely to use certified channels as compared to their counterparts in the Eastern region and the differences are statistically significant at 5 and 1 percent levels respectively. This underscores the vibrancy of the cassava subsector in the Mid-Western and Northern regions where cassava is a major cash and staple food crop than the Eastern region where millet, maize and other crops are more prominent than cassava. This quantitative finding corroborates the farmer reported rankings of the importance of cassava as a food security and commercial crop during the FGD conversations with farmers and KIIs with DAOs.

4.10 Conclusions and policy implications

In this chapter, the study discussed the characteristics of famers who source cassava seed from certified and uncertified sources, and empirically examined the determinants of seed source choice. The study empirical results indicate that farmer perceptions about the use of improved certified seed and seed sources, household decision-making and input access shocks play an important role in influencing farmers choice of a given seed source. For instance, the study finds a 12% to 13%

[21]These networks may be worth further investigation on their benefits

high likelihood of obtaining seed from certified sources when a husband and wife jointly make decisions. Farmers that are satisfied with seed inspection and certification services are 14-16% more likely to source seed from certified sources while limited access to improved seed was associated with a 7% less likelihood of sourcing seed from certified channels. Results further show that farmers that were visited by a government extension agent were 6-8% more likely to source their seed from certified channels. Contrary to what was hypothesized, the study did not find a significant relationship between the status of transport means and the choice of seed sources.

This study thus recommends that farmer development programmes and project initiatives should deliberately encourage households to discuss and make decisions jointly as opposed to individual decision-making which in most cases is flawed from limited information. In line with this, women's empowerment should be treated as critical in as far as it facilitates joint decision-making in the households.

Deliberate efforts aimed at changing farmer perceptions about seed access should be promoted. This can be achieved through targeted farmer training and extension services. Agricultural technology promotion should be carried out using Agricultural Innovation Systems (AIS) approaches so as to attain higher impact on farmers' mindsets. With the right information and guidance, farmers are able to make fully informed decisions resulting into better agricultural practices and consequently better productivity and welfare outcomes.

Increasing availability and access of improved certified seed should be a targeted venture. Government should fund decentralized cassava seed multiplication centres across farming communities. These seed multiplication centers should be inspected and certified according to proven and approved scientific and regulatory protocols. This together with a functional government extension system that provides farmers with information and guidance necessary to make informed decisions as well as illuminating the benefits of using improved certified seed would yield better farming outcomes. Through subsidized arrangements, farmers can be incentivized through the Operation Wealth Creation (OWC) national programme to access, at affordable premiums, seed from these multiplication centers or through certified Cassava Seed Entrepreneurs. The latter would then buy certified seed from the multiplication centers described above. This seed would then be further multiplied for sale to sensitized farmers who would, through effective extension services, be able and willing to buy.

4.11 Contribution to knowledge and literature

To the best of my knowledge, this is the first attempt to characterize and classify cassava seed sources into certified and uncertified sources in the cassava farming sub-system of Uganda. This is the first study to empirically examine the causal determinants of farmers' choice of cassava seed sources in Uganda. Moreover the probit model uses a rich set of variables including institutional factors, farmer perceptions, decision-making, wealth and asset variables including TLUs to explain causal determinants of farmers' choice of cassava seed sources. In the causal determinants analysis, the study used pre-intervention (2010) data to mitigate reverse causality challenges. The findings provide one of the first sets of empirical evidence to support seed inspection and certification programmes in Uganda; spousal roles in household cassava production decision-making as well as use of AIS concepts in technology promotion.

4.12 Study limitations and suggestions for further research

This study broadly categorized seed sources into certified channels (sources with inspection and certification services embedded) and uncertified sources. This led to lumping together of different seed sources. It would be interesting to study each source separately and this could be implemented using an endogenous multinomial logit regression analysis. It is therefore suggested that an empirical inquiry be undertaken to study the determinants of choice of each seed source in Uganda using the proposed robust methodology. The proposed inquiry would go ahead to study the reasons for satisfaction and dissatisfaction (farmer perceptions) about the different seed sources.

5 CHAPTER 5: IMPACT OF CASSAVA TECHNOLOGY ADOPTION ON HOUSEHOLD PRODUCTIVITY AND WELFARE

5.1 Chapter summary

Following a comparative descriptive assessment of adopters and non-adopters of cassava technologies, the study applied a two-part model to examine the determinants of adoption and adoption intensity of cassava technologies. This was followed with the estimation of the productivity and welfare impacts of cassava technology adoption and adoption intensity using Ordinary Least Squares (OLS), Propensity Score Matching (PSM) and Endogenous Switching Regression model (ESR). The results indicate that AIP membership, access to extension services, land size, education, family size, and age of household head are some of the determinants of adoption and adoption intensity of cassava technologies. For instance, AIP membership is associated with 30% and 70% higher likelihood of adopting improved certified seed as opposed to improved uncertified and local seed respectively. Also, the intensity of adoption is higher for AIP members compared to non-AIP members in a sense that the area allocated to improved certified seed is 0.96 acres higher for AIP members than for non-AIP members. Also, increasing the household average schooling years by one is associated with a 6% higher likelihood of applying improved certified seed compared to improved uncertified and local seed; and an increased area allocation to improved certified cassava seed growing by 0.85 acres. Further still, households which received extension in 2015 allocate 0.71 more acres of land to improved certified seed than their counterparts that did not receive extension. The study also obtained consistent results from OLS, PSM and ESR to the effect that use of improved certified cassava seed is productivity and welfare enhancing. For instance, ESR empirical results indicate that using improved certified cassava seed increases stem and root yield by 18 bags/acre (43.68 bags/ha) and 4.2 tones/acre (10.45 tones/ha) respectively while at the same time increases household total consumption expenditure and cassava cash income by 32% and 87% respectively. The study results generate evidence to support government policies aimed at increasing and sustaining public investments in variety genetic improvement, seed inspection and certification.

5.2 Introduction

To answer the individual research questions and test the specified hypotheses, this objective used data analysis methodologies in order[22] of robustness starting with mean comparison of productivity and welfare outcome variables between adopters and non-adopters then application of Ordinary Least Squares (OLS) regression, followed with Propensity Score Matching (PSM) and finally the application of Endogenous Switching Regression modeling (ESR).

Determinants of adoption and adoption intensity were studied using the Two Part Model (TPM). Mean comparison of outcome variables and OLS impact estimates suffer selection and endogeneity bias and therefore lack reliability in advising policy. While PSM controls for selection and endogeneity bias based on observable characteristics (e.g. age, education, wealth, extension and credit access), it falls short of controlling for bias due to unobservable characteristics like management skill, motivation, risk taking behavior, ambition). Thus PSM impact estimates may be said to be lacking full reliability in advising policy.

The most robust impact estimation methodology is ESR[23] which controls for bias due to both observable and unobservable characteristics. By adopting this approach, the study was able to test: (a) the hypothesis of whether there is equality of outcome estimates between cassava technology adopters and non-adopters and therefore be able to advise policy on the exact benefits of cassava technology adoption (b) the hypothesis of whether there is equality of outcome estimates obtained from the different estimation methodologies and therefore be able to generate evidence that it is possible to misadvise policy if you use weak identification strategies. To further conceptualize the study under this chapter, see figure 1.1 under section 1.4.

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[22] Note that the different analyses are all on the same issue which is impact of adoption and adoption intensity of cassava technologies on household productivity and welfare. The different analyses are separated in different sub-sections but flow into each other following order of robustness and rigour beginning with the least to the strongest.

[23] According to Lokshin and Sajaia (2004), models with endogenous switching can be fitted one equation at a time by either two-step least squares or maximum likelihood estimation. The problem is that both of these estimation methods are inefficient and require potentially cumbersome adjustments to derive consistent standard errors. The '**movestay**' stata command, on the other hand, implements the full-information ML method (FIML) to simultaneously fit binary and continuous parts of the model in order to yield consistent standard errors by relying on joint normality of the error terms in the binary and continuous equations.

5.3 Research objective and questions

Objective 3: To estimate the impact of cassava technology adoption on cassava productivity and household welfare

5.4 Research questions[24]

1. What are the socioeconomic characteristics of adopters and non-adopters of cassava technologies and what are the mean outcome differences between the two groups?
2. What are the causal determinants of adoption of cassava technologies?
3. What is the impact of improved-uncertified cassava seed adoption on household productivity and welfare?
4. What is the impact of improved-certified cassava seed adoption on household productivity and welfare?
5. Do different impact estimation strategies yield the same impact estimates?

5.5 Hypothesis tested

Hypothesis (iii)

The productivity and welfare outcomes of farmers using improved-certified cassava seed is higher than that of the farmers using improved-uncertified or local cassava seed

Hypothesis (iv)

There is equality of productivity and welfare estimates from the different impact estimation approaches used

[24] Note that this section differs from section 4.4 in a sense that while the latter was looking at technology access channels or sources, this section now looks at the real technologies being or not being adopted.

5.6 Descriptive socioeconomic characteristics of cassava farmers

5.6.1 Introduction

Under this first stage of analysis, the study compares outcome and explanatory variable estimates between the adopters and non-adopters and thereafter test for the mean difference significance following Ahimbisibwe and Mungatana (2012); and Wellard et al. (2015).

The ***outcome variables*** compared included: *productivity outcomes* (cassava stem yield (bags/acre), cassava root yield (Kgs/acre)), and *welfare outcomes* (cassava cash income adjusted by Adult Equivalent Units (AEUs), and household total consumption expenditure adjusted by AEUs); *food security outcomes* (number of meals per day, number of months the household was food insecure, food deprivation in 2015, household food consumption adjusted by AEUs); and the *Foster-Greer-Thorbecke (FGT) poverty outcome measures* (head count ratio-proportion below the 'poverty line'; the poverty gap index - a measure of the intensity of poverty; and the Squared Poverty Gap Index which weights the poor based on how poor they are).

The ***explanatory variables*** compared between adopters and non-adopters include: decision-making, gender of household head, farmer perceptions, seed access and farmer empowerment, credit access, group membership, social capital and networks, information access, transaction costs, household demographics, land access and wealth status variables. Besides exploring socio-economic background characteristics of the respondents, the purpose of this first stage analysis is to argue for the case that it is possible to make wrong inferences that interventions improve productivity and welfare even without properly identifying what is driving this improvement. Refer to appendix A5.1 for full results table.

Table 5.1: Descriptive statistics of cassava farmers

VARIABLE	IMPROVED CERTIFIED	SD	IMPROVED UNCERTIFIED	SD	LOCAL	SD		t-test		t-test
Variables	**Mean (A)**		**Mean (B)**		**Mean (C)**		**(A-B)**	**P-VALUE**	**(A-C)**	**P-VALUE**
Productivity outcomes										
Parcel stem yield (bags/acre)	47.909	43.598	36.702	37.911	37.304	112.289	11.207***	0.012	10.605	0.312
Parcel root yield (Kgs/Acre)	3153.789	2687.352	2836.906	2380.732	2518.173	1935.591	316.883	0.311	635.616	0.935
n	**97**		**200**		**305**					
Welfare outcomes										
PCHH Consumption Exp'000 (UGX)	1451.236	1952.586	1112.275	941.1793	977.4002	611.193	338.961**	0.043	473.836***	0.000
PCHH CassIncome'000 (UGX)	1927.632	5261.337	999.2572	6734.614	383.0803	2389.575	928.375	0.229	1544.552***	0.000
Food security outcomes										
1 if Food deprived in 2015	0.273	0.448	0.379	0.486	0.344	0.476	-0.107**	0.068	-0.072*	0.188
PC HH Food Expenditure	801418.9	483952.8	698628.8	436474.7	675351.2	398619.4	102790**	0.065	126067.7***	0.010
FGT Poverty outcomes										
Head count index (% poor)	0.513		0.681		0.743		-0.168			
Poverty gap index	0.179		0.284		0.301		-0.105			
Poverty severity index	0.081		0.148		0.151		-0.067			
Decision-making										
1 if husband decides	0.616	0.489	0.527	0.500	0.534	0.500	0.089*	0.145	0.082	0.156
Farmer perceptions										
1 if Satisfied with local varieties	0.202	0.404	0.236	0.426	0.462	0.499	-0.034	0.503	-0.260***	0.000
1 if Satisfied with modern varieties	0.808	0.396	0.754	0.432	0.439	0.497	0.054	0.292	0.369***	0.000
1 if Satisfied with seed inspection services	0.273	0.448	0.079	0.270	0.072	0.259	0.194***	0.000	0.201***	0.000
1 if Trust Farmer cassava seed channel	0.455	0.500	0.557	0.498	0.570	0.496	-0.102**	0.096	-0.116***	0.044
1 if Trust Govt cassava seed chanel	0.677	0.470	0.498	0.501	0.387	0.488	0.179***	0.003	0.290***	0.000
1 if Trust Govt NGO cassava seed chanel	0.424	0.497	0.315	0.466	0.203	0.403	0.109**	0.063	0.221***	0.000
1 if Trust Govt CSE cassava seed chanel	0.384	0.489	0.276	0.448	0.262	0.441	0.108**	0.057	0.122***	0.021
Seed access and shocks										
1 if Lack of improved varieties shock	0.525	0.502	0.537	0.500	0.705	0.457	-0.012	0.849	-0.180***	0.001
1 if Labor shortage shock	0.374	0.486	0.330	0.471	0.233	0.423	0.044	0.455	0.141***	0.006
1 if Lack of mechanization shock	0.737	0.442	0.591	0.493	0.731	0.444	0.146***	0.013	0.006	0.904
Group membership										
1 if HH is a member of an AIP	0.545	0.500	0.296	0.457	0.131	0.338	0.250***	0.000	0.414***	0.000
1 if HH head belongs to a group	0.879	0.328	0.759	0.429	0.738	0.441	0.120***	0.015	0.141***	0.004

1 if Received Govt Extension in 2015	0.333	0.474	0.153	0.361	0.085	0.280	0.181***	0.000	0.248***	0.000
Social Capital/Networks										
# of people rely upon when in need	30.626	35.005	30.700	59.097	21.466	25.428	-0.073	0.991	9.161***	0.005
# of people rely free cassava seed	14.929	14.583	16.813	39.508	15.669	31.007	-1.884	0.647	-0.740	0.819
Dependence ratio	0.948	0.688	1.248	0.866	1.393	0.937	-0.300***	0.005	-0.445***	0.000
Information access										
1 if had TV	0.232	0.424	0.108	0.312	0.075	0.264	0.124***	0.004	0.157***	0.000
1 if had Radio	0.838	0.370	0.660	0.475	0.695	0.461	0.178***	0.001	0.143***	0.005
Transaction costs										
1 if had motor-vehicle	0.081	0.274	0.044	0.206	0.013	0.114	0.036*	0.198	0.068***	0.001
1 if had motorcycle	0.293	0.457	0.222	0.416	0.128	0.334	0.071*	0.178	0.165***	0.000
1 if Poor transport means	0.566	0.498	0.527	0.500	0.456	0.499	0.039	0.529	0.110**	0.057
Household demographics and gender of HH Head										
# of Education school years of HH head	9.847	4.627	8.450	4.350	7.483	4.399	1.397***	0.011	2.364***	0.000
Age of HH head	48.480	13.962	46.680	14.479	44.317	13.717	1.800	0.309	4.163***	0.009
Family size	7.071	2.600	7.744	3.651	6.941	2.662	-0.673*	0.102	0.130	0.672
Land access										
HH Total land operated (Acres)	22.530	77.013	36.266	280.438	7.335	23.283	-13.736	0.633	15.195***	0.002
1 if land is rented in	0.121	0.328	0.054	0.227	0.062	0.242	0.067***	0.039	0.059**	0.056
Wealth status										
Tropical Livestock Units (TLUs) 2015	4.566	6.299	3.561	5.708	1.995	2.384	1.005*	0.166	2.571***	0.000
PCT AssetValue2015	1.47E+07	3.86E+07	8975282	2.46E+07	5232620	1.11E+07	5724718	1.23E-01	9467380***	0.000
n	***99***		***203***		***305***					

**** p<0.1 is significance at 10%; ** p<0.05 is significance at 5%; and *** p<0.01 is significance at 1%[25]***

[25] Variable abbreviations in full: PCHH= Per capita Household; TLUs= Tropical Livestock Units; PCT= Per capita total; HH= Household

Table 5.1 presents the characteristics of the farmers who applied improved and certified seed, improved and uncertified seed, and those who planted local seed. The study tests for the difference in the characteristics across the three seed types. The results show that farmers who applied improved and certified seed have significantly higher yield than those who applied uncertified seed or local seed. For instance, farmers who used improved certified seed harvested 47 bags per acre compared with 37 and 38 bags per acre for farmers who used improved uncertified seed and local seed respectively. These findings are in agreement with the 35-100 bags per acre stem yield recorded from various cassava production centers studied by NARO from 2014 to 2017 (NARO, 2017). It should be explicitly noted that there are no currently standardized stem yield national statistics because they vary from place to place in line with the changing circumstances. Stem yields will differ partly due to differences in varieties, management practices, weather patterns and soil fertility.

In addition, the welfare measures are more favorable for the farmers who used improved certified seed than those who planted improved uncertified and local seed respectively. Indeed, the per capita household consumption expenditure[26] for farmers who planted certified seed was 1,451,000 UGX, higher than 1,112,000 UGX and 977,000 UGX for the famers who applied uncertified and local seed respectively, and the difference is significant at 5%. The household per capita cassava income is also higher for the households that planted improved certified seed than those that planted improved uncertified or local seed.

With regard to individual contribution of stems and roots to cassava cash income, the latter was disaggregated into tuber and stem incomes for the pooled sample and for the different seed types (See appendix A5.2). While stem income is derived from stem seed sales only, tuber income is derived from sales of fresh tubers, dried chips, flour, cooked cassava, cassava cake, cassava bread and cassava beverage. Disaggregated results indicate that tuber income is consistently higher than stem income for the pooled sample and across different seed types. For

[26] Quantities measured and reported in nonstandard units were converted into standard units using conversion factors reported in the survey as well as the conversion factors used in the production and consumption modules of the Living Standards Measurement Study–Integrated Surveys on Agriculture (LSMS-ISA). Since literature reports a valid concern that households might systematically undervalue consumption from own production, care was taken to probe for correct valuations.

instance, when all seed types are pooled together, tuber income is higher than stem income by UGX 510,354. Disaggregating cassava cash income by seed type reveals that tuber incomes are higher than stem incomes by UGX 594,956, UGX 691,887 and UGX 362,069 when farmers use improved certified, improved uncertified and local cassava seed respectively. This is expected because while stems are only used for only one purpose (seed) and do not require any form of processing or value addition other than packaging; roots can be sold as fresh roots, and can also be processed through value addition into several products as shown above such that their value increases with the level of value addition.

Improved certified seed farmers also differ from improved uncertified and local farmers along other dimensions. For instance, 27% of farmers who planted improved certified seed reported that they were food deprived in 2015 compared to 38% and 34% of those who planted improved uncertified and local seed respectively. Also, the headcount index, a measure of how poor one is, indicates that 51% of famers who used improved certified seed were below the poverty line compared to 68% and 74% of those who planted improved uncertified and local seed respectively. These results suggest that farmers who planted improved certified seed are less food insecure and relatively few of them live below poverty line compared to those who planted uncertified and local seed (see figure 5.2). Since food insecurity is a multidimensional condition, affecting people through limited food availability, access, utilization, and stability; the study examined only a few indicators of food security for descriptive purposes. Barret (2010) reports that extended periods of poverty are among the major causes of food insecurity.

Besides directly contributing to the alleviation of food insecurity, agricultural technologies such as improved seeds have a special role in developing countries because they boost the performances of the agricultural sector and hence enhance the overall growth (Kassie et al., 2011).

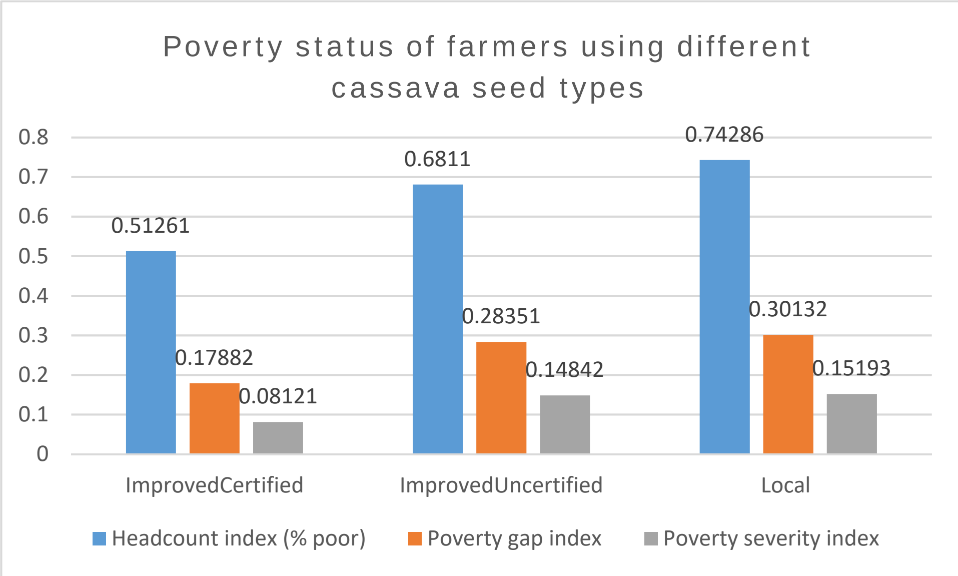

Figure 5.1: Poverty status of farmers using different cassava seed types
***Source*: Own data**

The statistics also indicate that the farmers who planted improved certified seed had positive perceptions about the use of modern seed varieties. For instance, 81% of the farmers who planted improved certified seed reported that they are more satisfied with modern varieties, compared to 75% and 43% of the farmers who planted improved uncertified and local seed respectively.

Regarding local seed, 20% of the farmers who used improved certified seed are satisfied with local seed, which is less than 24% and 46% of the farmers who planted improved uncertified and local seed, respectively. Related to this, very few farmers who planted improved certified seed reported that they trust farmer seed channels (46%) compared to 56% and 57% of the farmers who planted improved uncertified and local seed respectively. On the other hand, more farmers who planted improved certified seed trust certified seed channels compared to those who planted local or improved uncertified seed.

On group membership and extension service provision, more farmers who planted improved certified seed were members of Agricultural Innovation Platforms (AIPs), belonged to other farmer groups and they reported to have received extension services in 2015 than the farmers who planted local and improved uncertified seed. The statistics show that 55% of farmers that used improved certified seed were AIP members compared to 30% and 13% of those who used improved uncertified and local seed respectively, and the difference is statistically significant at 5%.

In addition, the people who used improved certified seed have strong social capital. Indeed, farmers who used improved certified seed reported that they had 31 people they could rely on when in need. Those who used local seed had 21 people they could rely on in times of need, and the difference is statistically significant. In terms of the dependence burden, the farmers who adopted improved certified seed are less burdened than those that applied improved uncertified and local seed.

The statistics also show that the farmers who applied improved certified seed had access to more communication channels than those who applied improved uncertified and local seed. For instance, 23% of farmers who used improved certified seeds own televisions, significantly higher than 11% and 8% of farmers who used improved uncertified and local seed, respectively. In addition, 84% of farmers who applied improved certified seed reported to be having radios, significantly higher than 66% and 70% of farmers who applied improved uncertified and local seed.

The statistics also reveal that more farmers who applied improved certified seed own transportation means such as motor-vehicles, and motorcycles, more than those who applied improved uncertified and local seed. For instance, 8% of farmers who applied improved certified seed reported that they owned motor vehicles which is significantly higher that 4% and 1% of farmers applied improved uncertified and local seed respectively. Likewise, 29% of farmers who applied improved certified seed own motorcycles, which is significantly higher than 22% and 13% of farmers who applied improved uncertified and local seed respectively.

According to the household characteristics, the heads of households that applied improved certified seed have higher schooling years (10 years) than those who applied improved uncertified seed (8 years) and local seed (7 years). In addition, the household heads of those that applied improved certified seed are older than those who applied improved uncertified and local seed. In terms of access to land, the households that applied improved certified seed have significantly more operated land (22 acres or 8.91 ha) than those who applied local seed (7 acres or 2.83 ha).

Also, the results indicate that the majority of households that applied improved certified seed planted it on land largely acquired through renting as compared to those who applied improved uncertified and local seed. Improved certified seed users had rented in additional land such that renting becomes their major mode of land access. The households which applied improved certified seed are wealthier than those that applied improved uncertified and local seed in terms of Tropical Livestock Units (TLUs) and asset value. During Focused Group Discussions (FGDs), farmers reported lack of capacity in terms of resources as being major hindrances to use of improved certified seed. They averred that one requires transport funds to be able to source and transport improved certified seed to their farms and that lack of the same occasions use of own saved seed. This underscores the importance of wealth status in adoption of cassava technologies and hence the need to control for wealth and asset variables during isolation of impact of cassava technology adoption.

5.7 Determinants of adoption and adoption intensity of cassava technologies

5.7.1 Introduction

This study attempts to empirically examine the determinants of adoption and adoption intensity of cassava technologies. From a policy perspective, it is imperative to understand the factors that drive households to seek and sustainably use the solutions (technologies) that are generated (usually with high level resource investments) to solve societal problems. Similarly, it is crucial to understand the factors that cause adopters to adopt to different levels. Accordingly, the study attempts to empirically examine the causal determinants of adoption and adoption intensity using the most appropriate econometric approach called the Two-Part model whose empirical strategy is presented in the next section. The two part model has two parts as the name suggests. The first part concerns the first decision node to adopt or not to adopt the technology. Therefore, the dependent variable is a binary choice dummy variable that takes on the value of 1 if the farmer decides to adopt the technology and 0 if otherwise. Thus, the first part of the model uses probit estimation.

But since farmers adopt to different levels, it is important to go beyond the decision to adopt and also examine the extent of adoption called adoption intensity measured by area in acres planted with the technology. This is because a farmer that plants one acre of the technology may be different in terms of productivity and welfare outcomes (benefits) from the farmer that plants 10 acres. In other words, different adoption intensities may be determined by different factors in the same way they lead to different productivity and welfare outcomes. Since area planted is a continuous dependent variable, the second part of the two-part adoption model uses OLS estimation procedure.

Both zero-inflated and hurdle models such as the two part model and double hurdle model respectively deal with the high occurrence of zeros in the observed data but differ in how they interpret and analyze zero counts. A zero-inflated model such as a two-part model assumes that the zero observations originate from both structural and sampling origins. The sampling zeros are due to the usual Poisson (or negative binomial) distribution, which assumes that those zero observations happened by chance (Nunes et al., 2011; Leung and Yu, 1996). Structural zeros are observed due to some specific structure in the data. For example, if a count of area planted with a cassava technology is the outcome, some adopters may score zero because they failed to get land; these are the structural zeros since they cannot allocate any land to planting of the cassava technology. Other adopters have land but score zero because they have not planted any cassava technology that they accessed. This implies that their adoption behavior is assumed to be on a Poisson or negative binomial distribution that includes both zero (the “sampling zeros”) and non-zero counts (Nunes et al., 2011).

According to Leung and Yu (1996), if a farmer is considered an adopter, then the double hurdle model assumes that the adopting farmer has no ability to allocate zero land to planting of the cassava technology that they accessed and will always score a positive number of acres of land allocated to planting of the new technology with either truncated Poisson or truncated negative binomial distributions. It is often argued that the distinction between structural and sampling zeros, and hence between zero-inflated and hurdle models, may seem subtle. However, one or the other models may be more appropriate depending on the nature of the study design and the outcome data being observed (Rose et al., 2006; Nunes et al., 2011). Next is a conceptual framework of the Two-Part Model.

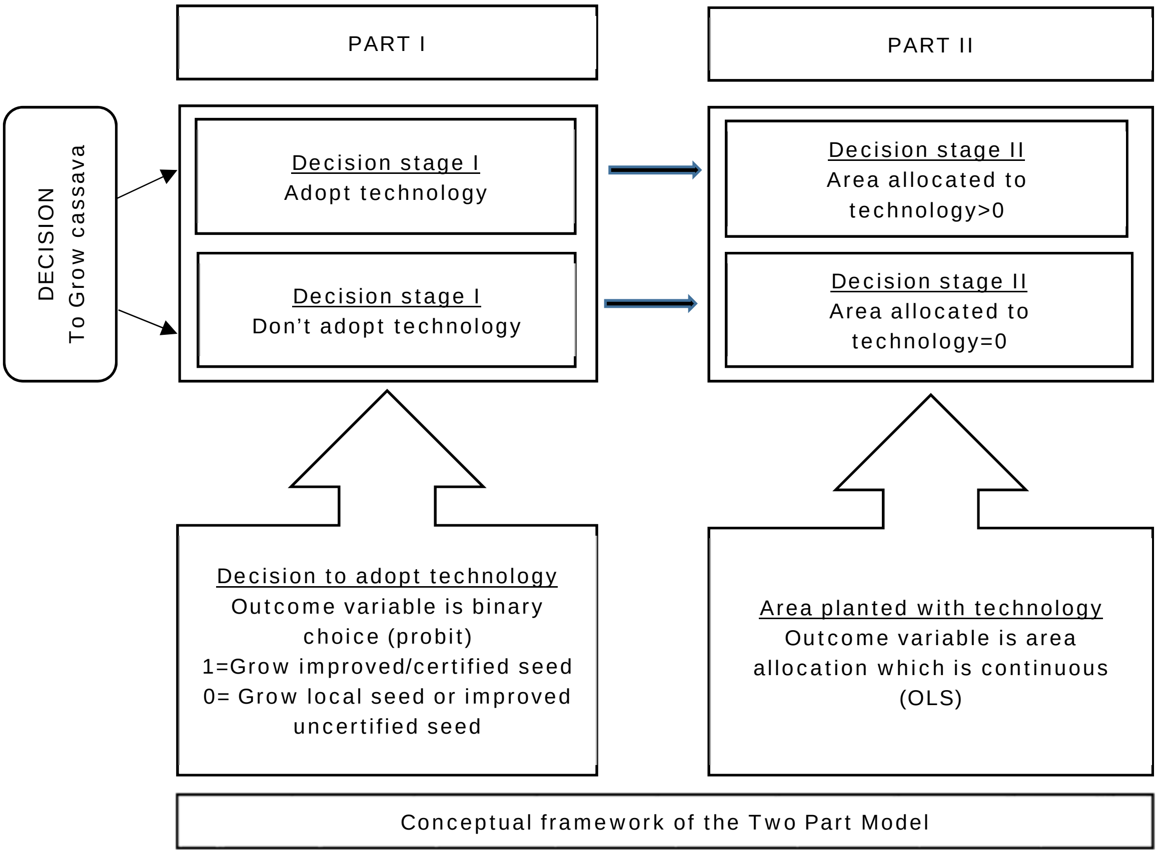

Figure 5.2: Conceptual framework of the two part model
(Source: Author's compilation)

5.7.2 Empirical strategy of the two-part adoption model

According to Humphreys (2013), Two-Part Models are appropriate when the zero outcome variable is a genuine zero in which case it means that the adopter has chosen not to plant any of the adopted technology. In addition, two-part models are appropriate when the participation and consumption decisions are chronologically sequential as is the case in this study. To the extent that the different models can yield different results with very different interpretations, our study appropriately used the two part model in far as it perfectly fits our study design and nature of data being analyzed for the causal determinants of adoption and adoption intensity of cassava technologies.

According to Bua (1998) and Jones (2000), limited dependent variables are dealt with using three econometric approaches: sample selection or selectivity, hurdle and two-part models. Sample Selection Models are appropriate when the outcome $y_i = 0$ because of a non-observable response. According to Humphreys (2013), an example of a Sample Selection Model approach is Heckman (1979), which is the Heckman selectivity model (probit for the selection equation and OLS plus the inverse Mills ratio term from the participation equation), sometimes called the "heckit" model. The sample selection model has a latent variable representation. This representation is:

$$y_i = \begin{cases} y_{2i}^* & iff\ y_{2i}^* > 0, \\ unobserved & otherwise \end{cases} \quad \text{(E5.1)}$$

To estimate a sample selection model: (a) estimate a Probit for adoption using the full sample, (b) compute the inverse Mills ratio from the fitted Probit results, and (c) estimate the adoption intensity equation using OLS with the inverse Mills ratio as an explanatory variable for observations with positive outcome.

In consideration of the decision-making process of adoption and then adoption intensity, the sample selection model thus becomes uninformative in estimating the determinants of the level of adoption. The other approach is hurdle models which too have a latent variable representation:

$$y_i = \begin{cases} y_{2i}^* & iff\ y_{2i}^* > 0\ and\ y_{1i}^* > 0 \\ 0 & otherwise \end{cases} \quad \text{(E5.2)}$$

Just like in sample selection models, hurdle models are appropriate when the adoption and adoption intensity decisions are made simultaneously. To circumvent this limitation, this study adopts the two-part model which is econometrically more appropriate when the adoption and adoption intensity decisions are chronologically sequential (Humphreys, 2013). The two-part model is estimated by a logit or probit model for the probability of observing a positive value of adoption along with OLS on the sub-sample of positive observations. Two-part models resemble the Heckman selectivity model, but do not include the inverse Mills ratio in the second part, and thus do not correct for selectivity.

There is no latent variable representation for the two-part model but instead it is motivated by a conditional mean independence assumption $E(y_i | y_i > 0, x_{2i}) =$

$x_{2i}\beta_2$. It may be important to note that two-part models are independently estimated adoption functions and adoption intensity functions. Humphreys (2013) concurs that the basic idea behind two-part models is that the adoption decision differs from the quantity (adoption intensity) decision in a fundamental way. The next section presents an elaboration of the probit and OLS empirical strategies as decomposed estimation constituents of the two-part model.

5.7.3 Empirical strategy of probit model

In this study, the dependent variable takes on the value of 1 if the household adopted the cassava technology and zero if otherwise. Estimating the qualitative response of a dummy dependent variable, according to Gujarati (2004), is done through three empirical strategies: linear probability model (LPM), logit model; and probit model. The linear probability model (LPM) is a typical regression model which would require a continuous dependent variable, but in the case of this study, the dependent variable is a dummy variable. Therefore, the conditional expectation of the dependent variable, given independent variables is interpreted as a conditional probability (i.e. the coefficient on the independent variable shows the magnitude of the likelihood effect on the binary dependent variable).

According to Gujarati (2004) and Wooldridge (2009), the linear probability model has considerable limitations which include: non-normality of the error term, the probabilities can be less than zero or greater than one, and the partial effect of any independent variable is constant. To circumvent these limitations, logit and probit models are suggested as limited dependent dummy variable estimation models. While the logit model is based on a logistic cumulative distribution function, the probit model follows a normal cumulative distribution function. Both the logit and probit probability models are able to circumvent the limitations of the linear probability model in the following ways: a) as the independent variable X_i increases, the probability of adoption (i.e., P_i = (Y=1|X) increases, but only in the 0-1 interval; and b) the relationship between P_i and X_i is nonlinear. Therefore, the probability approaches zero as X_i approaches negative infinity and the probability approaches one as X_i approaches positive infinity. Thus, because the logit distribution has bigger tails than the probit distribution, the conditional probability approaches zero or one at a slower rate in the logit than in the probit model (Gujarati, 2004).

Accordingly, the probit model is adopted to analyze farmers adoption decisions in as far as it is an appropriate econometric model for the binary outcome dependent variable whose error term is assumed to be normally distributed unlike in the logit model (Wooldridge, 2009). For this reason, the probit model is preferred to the logit model by most economists. In specifying the model, the study follows the works of Bua (1998), Zavale et al. (2005), Uaiene et al. (2009), Lopes (2010), and Mwesigye and Matsumoto (2016). The probit model estimates the effects of X_i on the response probability, P_i= (Y=1|X). The model assumes that households make decisions based on a utility maximization objective. The model assumes that the households' decision on whether or not to adopt cassava technologies depends on unobservable utility index (or a latent variable) that is determined by household specific attributes X (e.g., wealth status, socio-demographic factors like gender, age, and education; access to extension services, group membership, decision-making, etc.). The probit model of cassava technology adoption is derived from an underlying latent variable model, which is expressed as:

$$Y_i^* = \beta_0 + \beta_{ij}X_{ij} + e_i \quad \text{(E5.3)}$$

where $\boldsymbol{Y_i^*}$ is an underlying index reflecting the difference between the utility of adopting and not adopting the cassava technologies; β_0 is the intercept; β_{ij} is a vector of parameters to be estimated; X_{ij} is independent variables which explain cassava technology adoption, and e_i is the standard normally distributed error term that is independent of X_j and is symmetrically distributed about zero. From the latent variable model (E5.3) and the assumptions given, the household's adoption of cassava technologies is derived as:

$$P(Y_i^* = 1|x) = F\left(\beta_0 + \beta_{ij}\beta_{ij}\right) \quad \text{(E5.4)}$$

where F is the function that ensures the likelihood of adopting is strictly between zero and one. Thus, a household adopts cassava technologies if $Y_i^* > 0$, and otherwise if $Y_i^* \leq 0$. Taking a normal distribution function, the model to estimate the probability of observing a household adopting cassava technologies can be explicitly stated as:

$$P(Y_i^* = 1|x) = F(\beta X) = \int_{-\infty}^{\beta X} \frac{1}{\sqrt{2\pi}} exp(-Z^2/2)dz \quad \text{(E5.5)}$$

where P is the probability that the ith household adopted and 0 otherwise; X is the K by 1 vector of the independent variables; Z is the standard normal variable, i.e., $Z \sim N(0, \sigma^2)$; and β is the K by 1 vector of the coefficients to be estimated.

The essence of regression analysis is to estimate the marginal effect of an independent variable on the dependent variable while controlling for the influence of other independent variables (Gujarat, 2004). Unlike in linear regressions where parameter estimates can be interpreted as marginal effects, this study cannot do the same with non-linear regressions or binary dependent variable regressions like probit or logit unless we calculate the derivative of the outcome probability with respect to the independent variable.

In most applications of binary dependent variable regression models like probit, Gujarat (2004) and Wooldridge (2009) contend that the main aim is to explain the effects of the X_j on the probability regression $P_i(y = 1|X)$. The latent variable formulation (E5.3) indicates that the adoption model is primarily interested in the effect of each X_i (e.g. households receiving extension training) on Y_i^* (whether or not to adopt). Since this study's set of independent variables includes both discrete (binary) e.g. 1 if received extension and 0 if otherwise and continuous variables e.g. number of education years; Wooldridge (2009) explains that for the discrete or binary independent variables, partial effect from changing X_i from zero to one, holding other variables constant is given by:

$f(\beta_0 + \beta_1 + \beta_2 X_2 + \cdots + \beta_k X_k) - f(\beta_0 + \beta_2 X_2 + \cdots + \beta_k X_k)$,
(E5.6)

while for the continuous variables is given by $f(\beta_0 + \beta_X)\beta_j$
(E5.7)

5.7.4 Empirical strategy of OLS model

Ordinary Least Squares (OLS) regression is applied in studying the dependence of one variable on one or more variables with a view of estimating the population mean (Gujarati and Porter, 2009). By using OLS, Green (2003) argues that the average treatment effect is just an average partial effect measured by dummy variables taking on the value of one if the technology was used and zero otherwise. The OLS estimator is applied through the Linear Probability Model for studying determinants of adoption and is specified as $y_i = x_i\beta + e_i$ where y_i is an indicator variable for adoption, x_i is a vector of explanatory variables, β is a vector of unknown parameters to be estimated, and e_i is an unobservable random error term.

5.7.5 Data used in the study

This study used cross-sectional household survey data collected from 609 cassava farming households of Eastern, Northern and Mid-Western Uganda. Using a pre-tested structured questionnaire (Appendix A5.5), data was collected on a set of variables, inter alia, as presented in the next sub-section.

5.7.6 Description of variables used in the Two-Part adoption determinants model

Dependent variables

In the first part of the two part model, the estimation is through probit modeling since the dependent variable is a binary choice dependent variable. Therefore the dependent variables are 1 and 0 dummy variables which indicates whether or not a household adopted any of the cassava technologies respectively. In this regard, the probability of a household adopting the cassava technology is explained and estimated by: the sign, the statistical significance, and the magnitude of the parameter of estimates in the probit adoption model. Adoption of cassava technologies is categorized to cover all the five binary choice adoption forms. Thus the five dummy dependent variables are: (a) 1 if the farmer used improved seed (both certified and uncertified) and 0 if used local seed; (b) 1 if the farmer used improved certified seed and 0 if farmer used uncertified seed (both improved uncertified and local seed); (c) 1 if farmer used improved certified seed and 0 if farmer used improved uncertified seed; d) 1 if farmer used improved certified seed and 0 if farmer used local seed; e) 1 if farmer used improved uncertified seed and 0 if farmer used local seed.

In the second part of the two-part adoption model, estimation is by OLS since the depended variables are continuous variables (area in acres planted with the cassava technology). Thus the probit part in the two part model is complemented with adoption intensity measured by the area planted with cassava technology (in acres) in an attempt to examine determinants of adoption intensity. The second part of the two-part model is estimated using Ordinary Least Squares (OLS) since the dependent variables take on the continuous form measured in number of acres planted with the cassava technology. Thus another set of continuous dependent variables becomes areas planted (in acres) with the cassava technology that was adopted i.e. the variable that took on the value of 1 in the 1st part (probit) of the two part model.

Independent variables

The household's decision on whether or not to adopt cassava technologies and the decision on how much area to plant with the cassava technology (adoption intensity) are hypothesized to be associated with several independent variables. Accordingly, the study classifies the independent variables into five (5) categories: institutional factors; socio-demographics; wealth status, vulnerabilities and shocks, and regional dynamics.

***Institutional factors*:** Access to extension, credit services, all-weather roads (tarmac) and household membership in an Agricultural Innovation Platforms (AIPs) are dummy variables that take on the value of 1 if the household received extension and credit services; had access to an all-weather tarmac road and was a member of an AIP; and 0 if otherwise. According to literature (Bua, 1998; Khonje et al., 2015; Magrini and Vigani, 2016) both access to extension services and group membership exposes households to more information and learning opportunities and thereby increasing their chances of learning about the new agricultural technologies and their benefits. In deciding whether or not to adopt, households need information about the technologies and on the exact benefits accruable from adopting them. Such information can be attained through agricultural extension services and group memberships.

Credit access may enable farmers to afford costs associated with technology adoption (Bua, 1998; Khonje at al., 2015; Magrini and Vigani, 2016). Access to tarmac all weather roads may influence a farmer's adoption decision in as far as it reduces transaction costs and enables efficient mobility. For these reasons, this study included these four institutional independent variables to assess whether access to extension and credit services, access to all weather roads and AIP membership are associated with the household's decision to adopt new cassava technologies.

Socio-demographic characteristics**:** Under this category the study includes average education years of a household, age and gender of household head, and family size. Household average education years is a continuous variable that captures the total number of formal education years of all household members divided by the household size. Education level has implications on decision-making with regard to adoption of new technologies. Productivity in agriculture is higher for those with higher levels of education (World Bank, 2016b). Age of household head is also a continuous variable that may be associated with adoption of technologies because young and old farmers respond differently to innovations. Household head's gender is included as a dummy categorical variable that takes on the value of 1 if household head is female and o if male. The household head gender variable is included to control for and explain the cultural institutional limitations imposed on women with regard to free association. This study further includes family size as a continuous variable that shows the total number of people in a particular household. Family size has implications on the resources available for the wellbeing of a household and as such is included to assess its influence on the decision to adopt new cassava technologies.

Wealth status variables**:** This set of explanatory variables include number and value of livestock animals measured through Tropical Livestock Units (TLUs) owned by a household, asset value (UGX) of a household and total land operated in acres. Availability of resources may determine one's ability to adopt new agricultural technologies.

Vulnerabilities and shocks: The study includes high input price shock as a dummy variable that takes on the value of 1 if a household experienced it and 0 if otherwise. Shocks may significantly influence a household's ability to adopt a new agricultural technology especially if they are related to input access.

Regional dynamics: captured as dummy variables taking on the value of 1 if a household is domiciled in the Mid-western or Northern regions and 0 for eastern region. Regional dynamics are included to assess the influence of geographical location on household's agricultural technology decision-making process.

5.8 Empirical results and discussion of determinants of cassava technology adoption

For a full results table on the determinants of cassava technology adoption, see Appendix A5.

Table 5.2: Determinants of adoption of improved and certified cassava seed use and adoption intensity

	Improved Vs Local		*Improved Certified Vs Uncertified & Local*		Improved Certified Vs Improv. Uncertified		Improved Certify Vs Local		Improved Uncertify Vs Local	
VARIABLES	probit	glm	probit	glm	probit	glm	probit	glm	probit	glm
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1 if AIP member	0.463***	0.838***	0.481***	0.961	0.303	0.961	0.707***	0.961	0.409**	0.379
	(3.233)	(2.932)	(3.003)	(1.539)	(1.616)	(1.539)	(3.698)	(1.539)	(2.516)	(1.470)
1 if had tarmac	0.167	0.321	0.244	0.885	0.215	0.885	0.386*	0.885	0.0811	0.0955
	(1.214)	(1.139)	(1.558)	(1.490)	(1.168)	(1.490)	(1.958)	(1.490)	(0.524)	(0.361)
HHH Education Years	0.0591***	0.0850*	0.0501**	0.202**	0.0158	0.202**	0.110***	0.202**	0.0488*	0.0136
	(2.654)	(1.916)	(1.999)	(2.185)	(0.552)	(2.185)	(3.360)	(2.185)	(1.957)	(0.328)
1 if received Extension	0.208	0.715**	0.509***	0.250	0.458**	0.250	0.593***	0.250	0.00687	0.612**
	(1.364)	(2.310)	(2.982)	(0.382)	(2.276)	(0.382)	(2.855)	(0.382)	(0.0398)	(2.135)
1 if trained on Improved varieties	0.0191	-0.0652	-0.0973	1.078	-0.159	1.078	0.0465	1.078	0.0257	-0.275
	(0.0930)	(-0.169)	(-0.460)	(1.374)	(-0.654)	(1.374)	(0.175)	(1.374)	(0.108)	(-0.732)
1 if accessed credit	0.0319	-0.256	-0.0846	0.394	-0.138	0.394	-0.0452	0.394	0.0690	-0.474**
	(0.318)	(-1.165)	(-0.669)	(0.778)	(-0.924)	(0.778)	(-0.298)	(0.778)	(0.634)	(-2.508)
Land operated (Acres)	-0.00346**	-0.000627	-0.00362*	0.0340***	-0.00404	0.0340***	-0.00383	0.0340***	-0.00259	-0.00459
	(-1.993)	(-0.183)	(-1.647)	(2.834)	(-1.576)	(2.834)	(-1.208)	(2.834)	(-1.436)	(-1.620)
Log Asset value'000	0.0537	0.218**	0.0264	0.0768	0.00807	0.0768	0.0219	0.0768	0.0603	0.192**
	(1.156)	(2.226)	(0.457)	(0.344)	(0.124)	(0.344)	(0.308)	(0.344)	(1.166)	(2.189)
TLU 2015	0.0515***	0.0345	0.0290*	-0.0338	0.0222	-0.0338	0.0953***	-0.0338	0.0461***	0.0703**
	(3.145)	(1.100)	(1.695)	(-0.482)	(1.173)	(-0.482)	(3.362)	(-0.482)	(2.685)	(2.507)
Age of HH head	0.00243	-0.00622	0.00427	-0.0351*	0.00428	-0.0351*	0.00382	-0.0351*	0.00144	0.00670
	(0.628)	(-0.721)	(0.876)	(-1.799)	(0.730)	(-1.799)	(0.651)	(-1.799)	(0.342)	(0.875)
Family size	0.00496	-0.0293	-0.0374*	-0.223**	-0.0481*	-0.223**	-0.0452	-0.223**	0.0174	0.0358
	(0.282)	(-0.801)	(-1.649)	(-2.331)	(-1.903)	(-2.331)	(-1.523)	(-2.331)	(0.918)	(1.173)
High Input Cost Shock	0.212	-0.0995	0.311*	0.0794	0.265	0.0794	0.398*	0.0794	0.0978	0.107
	(1.348)	(-0.314)	(1.723)	(0.116)	(1.247)	(0.116)	(1.800)	(0.116)	(0.556)	(0.370)
1=Northern region	-0.0653	-0.349	0.610***	-1.275*	0.739***	-1.275*	0.663***	-1.275*	-0.339**	0.445*
	(-0.521)	(-1.254)	(3.899)	(-1.924)	(3.969)	(-1.924)	(3.494)	(-1.924)	(-2.402)	(1.705)
Constant	-1.234***	-1.029	-2.187***	2.771	-1.196*	2.771	-2.428***	2.771	-1.318***	-1.655**
	(-2.814)	(-1.123)	(-3.946)	(1.261)	(-1.907)	(1.261)	(-3.488)	(1.261)	(-2.720)	(-2.065)
Observations	712	712	712	712	367	367	462	462	595	595

*z-statistics in parentheses; * p<0.1 is significance at 10%; , ** p<0.05 is significance at 5%; and *** p<0.01 is significance at 1%*

Table 5.2 presents the results on the adoption determinants and adoption intensity of different cassava seed varieties, estimated using two part model. Specifications 1 & 2 present results on the determinants of improved seed (improved certified and improved uncertified) using local seed as a reference category. The results presented in specifications 3 & 4 show the determinants of improved certified seed adoption versus local and improved uncertified seed. For these specifications, the outcome variable takes 1 if the farmer adopted improved certified seed and 0 if the farmer adopted improved uncertified or local seed. Specifications 5 & 6 present results on the determinants of improved certified seed versus improved uncertified seed, while specifications 7 and 8 focus on the improved certified seed versus local seed in the analysis. Lastly specifications 9 & 10 present results on the determinants of improved uncertified seed versus local seed.

The results indicate that being an AIP member is associated with 46% higher likelihood of adopting improved (either certified or uncertified) seed as opposed to local seed. Also, the intensity of adoption (Specification 2) is higher for AIP members compared to non-AIP members. Specifically, the area allocated to improved seed is 0.84 acres higher for AIP members than for non-AIP members. Likewise, there is a high and significantly higher likelihood of adopting improved certified cassava seed compared to improved uncertified and local seed (specification 3), improved certified compared to local seed (Specification 7); and improved uncertified seed compared to local seed (specification 9). All these findings underline the importance of AIP membership which exposes member farmers to appreciating the benefits that come with growing quality certified planting material. With AIP membership comes consistent knowledge acquisition through repeated trainings and extension services, experience sharing among farmers and expert guidance from the AIP actors such as researchers and seed certification regulators (Mapila et al., 2012).

In addition, the results show that consistently, across all the specifications, the average household schooling years and the dummy indicating whether the household received extension services in 2015 are associated with a high likelihood of applying improved seed and a high adoption intensity. These findings are in agreement with those of Bua (1998). For instance, increasing the household average schooling years by one is associated with a 6% higher likelihood of applying improved certified seed compared to improved uncertified and local seed (specification 1), and increased area allocated to improved certified cassava seed growing by 0.085 acres (specification 2). The results remain consistent across different specifications and are robust to the changes in reference variables.

The magnitude of the impact becomes strong when improved certified seed is compared with local seed. The likelihood of applying improved certified seed is 11% higher for the households with an extra average one schooling year and an extra schooling year leads to an increase of land allocated to improved certified seed by 0.202 acres. While results indicate that access to tarmac road is positively associated with adoption of better farming technologies, the association is not significant.

The results show that households that received extension services in 2015 have a higher and significant likelihood and intensity of adopting improved seed, and allocated more land to that effect. For instance, a look at the general use of improved seed reveals that the households which received extension in 2015 allocate 0.71 more acres of land that their counterparts that did not receive extension. These results are consistent across all the specifications.

The family size and the age of the household head are negatively associated with the likelihood of applying improved seed, and the intensity of adoption. These results are as expected because a large family size means high cost of family maintenance which leaves little to be put to the purchase of improved seed. This corroborates findings from FGDs in which some farmers reported both old age and many dependents as being deterrents to adoption of cassava technologies.

Also, land size is negatively associated with a less likelihood of adopting improved seed. The finding that those with bigger land have a less likelihood of applying improved seed is consistent with the Boserupian hypothesis which states that land scarcity induces technology adoption (Bosrup, 1965). This might be attributed to the fact that farmers with large land sizes can keep soil fertility through fallowing and fertility of soils has a potential to keep the yields of local seed high.

5.9 Impact of cassava technology adoption

5.9.1 OLS Impact of cassava technology adoption on productivity

5.9.1.1 Introduction

Hypothesis (iv) of this study was about understanding if different impact estimation methodologies yield related impact estimates. This is intended to contribute to the argument that impact evaluations should always be carried out using rigorous methods that have frontier robustness checks so that the impact estimates generated are reliable. This is because it is possible to mis-advise policy if weaker methods such as OLS are used to estimate impact. On account of this reason, OLS is applied in the analysis under this sub-section mainly as a way of building the robustness check process.

This subsection presents the effect of technology adoption on cassava productivity and household welfare. On productivity, this study used cassava stem yield (bags/acre) and root yield (Kgs/acre) as key indicators. In addition, the study used per capita household consumption expenditure and per capita household cassava income as measures of welfare.

5.9.1.2 OLS Empirical strategy

Ordinary Least Squares (OLS) regression is applied in studying the dependence of one variable on one or more variables with a view of estimating the population mean (Gujarati and Porter, 2009). By using OLS, Green (2003) argues that the average treatment effect is just an average partial effect measured by dummy variables taking on the value of one if the technology was used and zero otherwise.

Letting Y_{pisj} be either stem or root yield from parcel p, belonging to household i in district d, the study runs the following regression:

$$Y_{pid} = \alpha + \beta ImprovSeed_{pid} + \vartheta M_{pid} + \partial X_{id} + v_d + \mu_{pid} \qquad \text{(E5.8)}$$

where $ImprovSeed_{pid}$ is a vector of dummy variables that take 1 if the household used certified or uncertified seed, and 0 if the household used local seed. In different specifications, $ImprovSeed_{pid}$ is a continuous variable showing the size of land that is allocated to certified seed. M_{pid} is a vector of parcel controls such as distance to the parcel (in kilometers), whether the parcel is rented, on customary land and title holding. X_{id} is a vector of household controls including household head gender, age, and average years of schooling, household assets, whether household owns a TV, radio and whether the household is an AIP member. v_d Captures district fixed effects, while μ_{pid} is an error term that may be heteroskedastic and correlated within a district. This is adjusted for by using robust standard errors and covariance matrices that allow for "clustering" of the error terms at a district level (see Wooldridge, 2010, Chapter 20).

Following this estimation, the results were subjected to a set of diagnostic tests to ensure none of the OLS assumptions is violated. These tests included heteroskedasticity using the Cock-Weisberg test, multicollinearity using the VIF test, and lastly the Ramsey Reset test for omitted variables.

The same specifications are used for welfare only that the dependent variables are welfare measures described in earlier sections. Also, the analysis shifts to the household level and not plot level as for yield. The study drops only parcel level variables in the analysis. Green (2003), however discussed that the use of OLS leads to spurious estimates because of the econometric endogeneity problem occasioned by the potential correlation that may exist between the error term and the regressor treatment dummy variable. Besides imposing linearity on the parameters, the OLS technique ignores the fact that the adopters may have different observable and non-observable characteristics from the non-adopters which may influence the outcome variable. Because of the failure of OLS to control for these pre-existing differences between adopters and non-adopters, Caliendo and Kopeing (2005) conclude that the OLS technique may lead to biased estimates. This second stage analysis too is purposed to demonstrate that causal effect identification using non rigorous approaches may lead to wrong conclusions.

5.9.1.3 Empirical results and discussion on productivity effects of cassava technology adoption

Table 5.3: OLS Productivity impact of improved and certified seed adoption

VARIABLES	Dependent variable is cassava stem yield (bags/acre)				Dependent Variable is cassava root yield (Kgs/acre)			
	Effect of Adoption		***Effect of adoption intensity***		***Effect of Adoption***		***Effect of adoption intensity***	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1 if used improved seed	7.177**				426.2**			
	(2.490)				(2.199)			
1 if used improved uncertified		5.776*				452.7**		
		(1.864)				(2.147)		
1 if used improved certified		10.96***				363.2		
		(2.601)				(1.313)		
Area Improved seed			-0.326				29.33	
			(-0.380)				(0.496)	
Area improved certified				0.631				-92.50
				(0.650)				(-1.479)
1 if AIP member	10.76***	10.36***	12.19***	11.56***	-144.5	-138.5	-93.79	-16.60
	(2.725)	(2.617)	(3.048)	(2.905)	(-0.555)	(-0.530)	(-0.357)	(-0.0635)
HHH Education years	0.346	0.338	0.475	0.437	1.537	1.137	9.140	14.71
	(0.561)	(0.548)	(0.767)	(0.706)	(0.0374)	(0.0276)	(0.222)	(0.358)
1 if received extension	-7.784**	-8.271**	-7.127*	-7.430*	186.1	195.1	217.2	252.9
	(-2.059)	(-2.176)	(-1.873)	(-1.954)	(0.758)	(0.788)	(0.880)	(1.028)
TLU 2015	0.747	0.714	0.895*	0.841*	-48.45	-48.09	-44.18	-36.08
	(1.621)	(1.548)	(1.926)	(1.820)	(-1.594)	(-1.580)	(-1.432)	(-1.182)
1 if own TV	2.106	1.596	2.631	2.101	519.8*	530.1*	527.4*	617.5**
	(0.446)	(0.337)	(0.550)	(0.441)	(1.682)	(1.704)	(1.675)	(1.977)
1 if suffered drought shock	-2.998	-3.143	-2.565	-2.695	-500.2***	-499.3***	-471.9**	-456.4**
	(-1.047)	(-1.098)	(-0.893)	(-0.938)	(-2.628)	(-2.621)	(-2.475)	(-2.397)
1 if mid-western region	4.148	3.793	4.246	3.883	1,026***	1,031***	1,048***	1,098***
	(1.104)	(1.007)	(1.121)	(1.024)	(4.065)	(4.073)	(4.124)	(4.326)
1 if Northern region	19.00***	18.19***	18.71***	18.65***	1,782***	1,794***	1,794***	1,811***
	(5.314)	(5.003)	(5.212)	(5.195)	(7.420)	(7.369)	(7.435)	(7.524)
Constant	32.17**	32.80**	31.46**	32.36**	2,277**	2,260**	2,280**	2,173**
	(2.482)	(2.530)	(2.407)	(2.482)	(2.579)	(2.553)	(2.559)	(2.453)
Observations	693	693	693	693	564	564	564	564
R-squared	0.093	0.095	0.085	0.085	0.151	0.152	0.144	0.147

t-statistics in parentheses; * p<0.1 is significance at 10%; , ** p<0.05 is significance at 5%; and *** p<0.01 is significance at 1%

Table 5.3 presents OLS results on the yield (cassava stem and root) impact of improved and certified seed adoption. The dependent variable for specifications 1 to 4 is cassava stem yield, while that for specifications 5 to 8 is cassava root yield. The main variables of interest are dummies indicating whether a farmer applied improved certified seed, or improved uncertified seed, or both (see specifications 1, 2, 5 & 6). The area allocated to either seed type is also used so as to ascertain the effect of adoption intensity on stem and root yield (specifications 3, 4, 7 & 8). In agreement with Bua (1998) and World Bank (2006) the results show that the households that adopted improved cassava seed have a significantly higher stem and root yields than the households that used local seed. For instance, farmers who used improved seed (whether certified or uncertified) had more 7 bags of cassava stem harvested per acre compared to those who planted local seed and the difference is statistically significant at 1 percent level of significance (see specification 1).

In specification 2, the analysis breaks down improved seed use into improved certified and improved uncertified to ascertain whether there is a differential impact of these two seed types on cassava stem yield. Indeed, the results indicate that those who planted improved certified seed had more stem yield than those who planted improved uncertified cassava seed. Using local seed-use as a reference, the results show that farmers who planted improved certified seed harvested about 11 bags of cassava stem more than those who planted local seed. On the other hand, farmers who planted improved uncertified seed harvested 6 bags of stem on an acre more than those who planted local seed. These results indicate that farmers who adopt any form of improved seed obtain a significantly higher yield than those that apply local seed but farmers who apply improved certified seed obtain more yield than those who apply other kinds of seed.

The results remain consistent when the analysis uses cassava root yield as the dependent variable (specifications 5 and 6). The results show that farmers who planted either improved certified or improved uncertified had 426 Kgs of cassava root than those who planted local seed. However, the results do not show any effect of adoption intensity on either stem or root yield. This might be explained by the commonly observed inverse relation between land size and yield (Carletto et al., 2016; Gourlay et al., 2017; Kilic et al., 2017) which suggests that productivity reduces with an increase in land size due to limited intensification on large lands. In relation to that, it might be that farmers who plant improved seed on larger parcels do not conduct full monitoring, weeding or even do not apply all the required inputs owing to increased labour requirements which in turn affects yield. Other variables that affect both stem and root yield include AIP membership, whether a household has a TV which positively affects yield; and the drought shock which negatively affects root yield.

5.10 OLS Impact of cassava technology adoption on household welfare

5.10.1 Introduction

The analysis of the impact of improved seed use on yield shows high and significant impacts of use of improved certified seed on stem and root yield. In this section the study probes further whether this increased yield translated into better welfare by looking at the effect of the technology adoption on per capita household consumption expenditure and per capita household cassava cash income. For full results table, see appendix A5.

5.10.1.1 Results and discussion on welfare effects of cassava technology adoption

Table 5.4 presents OLS results on the welfare effects of improved seed use. The dependent variable in specifications 1,2, 5 & 6 is the household per capita consumption expenditure in '000 Uganda Shillings (UGX), while the dependent variable in specifications 3,4,7 & 8 is the household per capita cassava cash income in UGX '000. Consistent with the OLS yield results, the study finds positive and significant effects of adoption of improved seed varieties on welfare measures. The study findings thus further reinforce those found by Asfaw (2012 a&b), Kuntashula and Munagtana (2013); Bezu et al. (2014), Shiferaw et al. (2014), Mmbando et al. (2014); Kassie et al. (2015), Khonje et al. (2015) and Magrini and Vigani (2016) to the effect that agricultural technology adoption is welfare enhancing.

Table 5.4: OLS Welfare effects of cassava technology adoption

	Effect of adoption				*Effect of adoption intensity*			
VARIABLES	**Log of per capita HH consumption expenditure (UGX'000)**		**Log of per capita HH cassava cash income (UGX'000)**		**Log of per capita HH consumption expenditure (UGX'000)**		**Log of per capita HH cassava cash income (UGX'000)**	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1 if used improved seed	0.00357		0.724***					
	(0.0913)		(3.942)					
1 if used improved uncertified		-0.0187		0.537***				
		(-0.446)		(2.730)				
1 if used improved certified		0.0631		1.222***				
		(1.109)		(4.580)				
Area improved seed					0.0123		0.354***	
					(1.064)		(6.669)	
Area improved certified						0.0233*		0.322***
						(1.783)		(5.271)
HH Education years	0.0529***	0.0529***	0.0913**	0.0907**	0.0523***	0.0521***	0.0843**	0.0909**
	(6.346)	(6.342)	(2.328)	(2.322)	(6.281)	(6.267)	(2.195)	(2.341)
1 if received extension	0.0573	0.0501	0.609**	0.549**	0.0528	0.0507	0.524**	0.566**
	(1.119)	(0.975)	(2.529)	(2.277)	(1.030)	(0.991)	(2.218)	(2.370)
TLU 2015	0.0238***	0.0235***	0.0345	0.0317	0.0230***	0.0228***	0.0198	0.0292
	(4.207)	(4.148)	(1.295)	(1.195)	(4.052)	(4.036)	(0.757)	(1.104)
1 if own TV	0.239***	0.230***	0.438	0.358	0.231***	0.228***	0.234	0.322
	(3.772)	(3.604)	(1.470)	(1.199)	(3.620)	(3.592)	(0.797)	(1.085)
Family size	-0.0830***	-0.0822***	-0.156***	-0.150***	-0.0826***	-0.0815***	-0.140***	-0.131***
	(-12.69)	(-12.54)	(-5.081)	(-4.868)	(-12.62)	(-12.41)	(-4.632)	(-4.274)
Log of asset value (UGX'000)	0.0727***	0.0725***	0.314***	0.312***	0.0717***	0.0716***	0.301***	0.315***
	(4.058)	(4.048)	(3.725)	(3.718)	(4.007)	(4.010)	(3.645)	(3.776)
1 if suffered pest shock	0.0339	0.0346	-0.347*	-0.342*	0.0328	0.0326	-0.331*	-0.314
	(0.785)	(0.801)	(-1.710)	(-1.690)	(0.763)	(0.758)	(-1.665)	(-1.562)
Constant	6.173***	6.183***	0.599	0.686	6.187***	6.188***	1.000	0.789
	(35.24)	(35.29)	(0.728)	(0.835)	(35.24)	(35.36)	(1.236)	(0.966)
Observations	700	700	700	700	700	700	700	700
R-squared	0.397	0.399	0.205	0.213	0.398	0.400	0.237	0.219

t-statistics in parentheses; * p<0.1 is significance at 10%; , ** p<0.05 is significance at 5%; and *** p<0.01 is significance at 1%

Results also indicate that high adoption intensity is significantly welfare improving (see specifications 5 to 8 in Table 5.4). For instance, an extra acre allocation to the growing of improved certified seed leads to a 2.33% increase in per capita consumption expenditure and 32.3% household per capita cassava income (specifications 6&8).

Other factors that are welfare improving are: household average schooling years, access to extension services, livestock ownership, television ownership and assets, while those that negatively affect welfare are family size and crop pest & disease shocks. The larger the family size, the smaller the consumption expenditure and cassava cash income per capita. Results indicate that an extra year of education of a family member on average increases household per capita total consumption expenditure and per capita cassava cash income by 5.3% and 9.1% respectively. The results remain consistent and significant across all the specifications. Wealth measures such as Tropical Livestock Units (TLUs) and assets are associated with high per capita cassava cash income and household total consumption expenditure. This is expected because relatively rich households spend more than their poor counterparts.

5.11 Estimating causal effect of cassava innovations on cassava productivity and household welfare using robust identification strategies (PSM and ESR)

5.11.1 Introduction

Due to non-random nature of the intervention, the methods used thus far (Mean comparison of outcome variables and OLS) in the first and second stage analysis may still suffer from endogeneity concerns in as far as they fail to control for selection and endogeneity problems leading to inappropriate policy conclusions. In this section, the study presents stage three and four analyses in which it controls for the selection and endogeneity problems caused by observable and unobservable characteristics of farmers and their farms by first applying a non-parametric regression technique (Propensity Score Matching) which corrects for the observable covariates only and then complements it with the estimation of a simultaneous equation model with endogenous switching regression using Full Information Maximum Likelihood Estimation (FIMLE) which corrects for both observable and unobservable covariates.

The fundamental evaluation (impact assessment) problem results from the simple fact that one cannot observe the counterfactual corresponding to any technological or policy change being considered (Asfaw, 2010). In other words, if a technological or policy change does occur, one cannot observe what would have happened to the various outcomes in the absence of the change if it did not occur, then one cannot observe what would have happened if the change did actually take place. This inability to observe the counterfactual in any impact assessment study is the reason why impact assessment is viewed from a statistical perspective as a problem of missing data (the counterfactual). In fact, the statistical procedures used to derive unbiased estimates of impact outcomes are in essence designed to create an environment or a set of data that reflect as closely as possible the missing counterfactual (Asfaw, 2010). The fundamental problem to solve is how one can evaluate the aggregate impact when every element in the summation has missing data (Diagne, 2006, Diagne and Demont, 2007 and Alene et al., 2007).

Thus, the counterfactual outcomes or Average Treatment Effects (ATE) framework is an impact methodology approach underlying modern evaluation theory and practice. Recent methodological advances in this area such as Blundell and Costa Dias (2000); Imbens and Angrist (1994); Imbens (2004); Wooldridge (2005); Angrist and Pischke. (2009); Asfaw (2010); Madola et al. (2011); Asfaw (2012 a&b); Mungatana & Kuntansula (2013); Shifferaw et al. (2014); Kassie et al. (2015), Khonje et al (2015) and Magrini and Vigani (2016) have set new standards of rigor for impact assessment that emulates the set-up of controlled experiments in such a way that the results of the analysis of observational data from surveys can be given similar causal interpretation.

This approach is employed through community and household surveys on knowledge and adoption of varieties and on seed acquisition; household and plot level surveys to collect data on areas and yield by variety, input use, income, food intake; estimation of dynamic models of adoption and impact based on the ATE methodology; and estimation of ex post impact on economic and environmental outcomes. The next section presents the data and description of variables used in both the Propensity Score Matching and Endogenous Switching Regression impact estimation methodologies.

5.11.2 Data and description of the variables

Outcome variable

Following Asfaw et al. (2011), Mmbando et al. (2014), and the justification discussed above in section 1.2, this inquiry used household cassava cash income adjusted by adult equivalents (hereinafter referred to as per capita household cassava cash income) and household total consumption expenditure adjusted by adult equivalents (hereinafter referred to as per capita household consumption expenditure) as proxy indicators for household welfare. According to Magrini and Vigani (2016), per capita household total consumption expenditure has been used as a proxy for household income while many other authors have used it as a proxy for food security (e.g. Amare et al., 2012; Asfaw et al., 2012a&b; Kathage et al., 2012; Awotide et al., 2013), on the basis that at lower income, the total consumption is limited and so is the expenditure dedicated to food and beverages. This makes it a powerful outcome variable in the context of this study.

The consumption expenditure data was collected for the preceding year covering a 12-month period using a standardized questionnaire developed following the LSMS-ISA standard tools which makes the findings of this study comparable to national and regional contextual statistics. The data was collected on purchased items and the amount spent during each spending period (week, month or year) and then aggregated to the annual level. The standard per capita consumption indicator of household welfare is based on food (household's own consumption of home produced food) plus purchased food, plus aid or gift food) and non-food expenditure adjusted by adult equivalent units. Household productivity was measured using cassava stem yield (bags/acre) and cassava root yield (Kgs/acre).

Treatment or dependent variable

Besides soil fertility, area and yield estimation, one other major challenge in agricultural data collection is the inability of farmers to correctly identify varieties. Most farmers lack full capability to distinguish between improved and local varieties especially when they have grown them for quite a number of years. To circumvent this potential source of error, researchers are proposing DNA indexing of sample collections done during surveys. However, this study recognizes the cost implications of sample collection and DNA indexing to correctly ascertain the varieties being grown by farmers. This study therefore opted to increase variety identification accuracy by further asking farmers to recall the main source of the seed they planted. This way, the study was able to classify seed according to source.

To the best of my knowledge, this is one of the first studies that has successfully attempted this novel approach in reducing farmer error of variety identification in relation to the cassava commodity. In the analysis, the study aimed at estimating the impact of adoption of cassava seed majorly sourced from NARO, NAADS and certified CSEs – all of which are improved seed sources that have seed inspection and certification services embedded. The study applied the robust Propensity Score Matching (PSM) and Endogenous Switching Regression modelling (ESR) impact estimation techniques to estimate the productivity and welfare impact of improved-certified seed adoption using improved-uncertified or local seed as the reference categories.

Therefore, the dependent variable in both the PSM and the ESR was the binary response dummy equaling to 1 if the household adopted the improved certified cassava seed and equal to 0 if otherwise.

Explanatory or independent variables

Following Magrini and Vigani (2016), the choice of the explanatory variables is driven by both theoretical and empirical considerations. In order to fulfil the CIA in PSM estimation, Caliendo and Kopeinig (2008) observe that the matching procedure imposes the selection of covariates, which influence the adoption decision but also the outcome variables (productivity and welfare indicators). It is further argued that the covariates must not be affected by the technology adoption or the anticipation of it. This leads us to select only covariates which are not affected by time or are clearly exogenous to the treatment.

Accordingly, household characteristics which included household head age and its square, household head gender, education level and family size were used. Wealth effect and training participation were captured using total value of household assets, household land endowments and livestock ownership adjusted to Tropical Livestock Units (TLUs). Alen et al. (2008) and Mmbando et al. (2014) posit that these variables are critical in production that enables households to produce surplus for the market.

Empirical evidence (Feder et al., 1985 and Magrini and Vigani, 2016) shows that there exists a positive relationship between technology adoption and farm size, given that smaller farms may be affected by higher fixed costs that discourage the adoption of new technologies. Magrini and Vigani, (2016) explain that the exogeneity is ensured by the fact that each household owns a very limited amount of land, mainly cultivated for subsistence purposes, and they are cash and credit constrained, hence there are very limited possibilities for them to allocate more land to cassava cultivation, despite being encouraged by the higher productivity.

Following Mmbando et al. (2014), transaction costs were captured through access to an all-weather road, while shocks and vulnerabilities were captured through drought, flood, crop pests and diseases as well as high input costs. According to Asfaw et al. (2012a), access to an all-weather road affects the transaction costs in marketing agricultural inputs and the access to information. While membership to an Agricultural Innovation Platform (AIP) and total number of people relied upon (social capital) are included as proxies for institutional support, knowledge and information sources such as access to extension and credit, TV ownership, government seed sources and trainings are captured as proxies for fixed transaction costs.

In literature (Asfaw et al., 2012a, Magrini and Vigani (2016), access to extension services is considered a main channel for getting information and awareness about new technologies, but also for building human capital. It is through extension that farmers learn about the advantages of new technologies and make decisions to adopt them. This study therefore used a binary variable equal to 1 if the household received extension services in the past 12 months, and 0 otherwise. It should be noted that in situations where extension services are unavailable or insufficient, other sources like radio, agro-dealers and fellow farmers play the leading role in awareness creation about new technologies.

According to Magrini and Vigani (2016), the contact with extension agents informing farmers on innovation clearly occurs before adoption, avoiding any reverse causality problem. A binary variable was included on credit access equal to 1 if anyone accessed credit and 0 otherwise because credit availability is considered in the literature (Feder et al., 1985; Magrini and Vigani, 2016) as a precondition for adoption of agricultural innovation and lack of credit can significantly limit the adoption also in the case of low fixed costs. In this regard, access to credit is clearly exogenous.

As suggested by Mmbando et al. (2014), the unobserved location-specific effects were controlled using regional dummy variables so as to capture differences in the household welfare conditions that might arise due to infrastructure, remoteness, resource endowment, production potential and farming conditions across districts and regions. These structural factors can be considered exogenous to the treatment because either they are fixed over time, beyond the household's control, or happened before the decision to adopt new technologies (Magrini and Vigani, 2016).

5.11.3 Summary of data analysis and computational methods

To perform several analytical procedures for empirically estimating the impact of cassava technology adoption and adoption intensity on productivity and welfare, this study used STATA/SE Version 13.1 to effect randomization in the selection of the households. The study first analyzed the means and proportions for the whole sample and then compared the characteristics between adopters and non-adopters of cassava technologies. These and other identified characteristics were later used as explanatory variables in the adoption and adoption intensity determinants two-part model, estimation of the Ordinary Least Squares impact model (OLS), propensity score estimation, treatment and outcome model estimation through Propensity Score Matching (PSM) and Endogenous Switching Regression modeling (ESR).

The explanatory variables used in the adoption determinants as well as the impact of adoption and adoption intensity analyses were selected basing on literature review, economic theory and the researchers' experience with the cassava farming communities. Following the works of Kuntashula & Mungatana (2013), the propensity scores were estimated using logit regression in which the dependent variable equaled to1 if the household had adopted the technologies and zero otherwise. Various specifications of the logit model were attempted until the most complete and robust specification that satisfied the balancing tests was obtained.

Using the estimated propensity score, the estimation of the Average Treatment Effect on the Treated (ATT) on several selected outcome variables was implemented. During matching, the sample was bootstrapped fifty times to obtain standard errors. The nearest neighbour matching (ATTnd), kernel matching (ATTk) and caliper radius matching (ATTr) stata version 13 commands were then used to estimate the average treatment effect of the cassava technologies on household productivity and welfare.

To test for matching results robustness and account for unobservable selection bias, the productivity and welfare outcome variables were subjected to endogenous switching regression analyses as proposed by Asfaw (2010) and applied by Kuntashula & Mungatana (2013), and Mmbando et at. (2014). Endogenous Switching Regression was used to predict and compute productivity and welfare outcomes using the *movestay* command proposed by Lokshin and Sajaia (2004). The next section presents the non-parametric impact evaluation approach using Propensity Score Matching.

5.12 Impact of improved certified seed adoption on household productivity and welfare using PSM

5.12.1 Introduction

Propensity Score Matching[27] (PSM) is one of the most commonly used quasi-experimental methods to address the evaluation problem (Mendola, 2007; Nkonya et al., 2007; Asfaw, 2010; Akinlade et al., 2011). The aim of PSM is to find the comparison group (counterfactual) from a sample of non-adopters that is closest to the sample of adopters based on observable characteristics so that by comparing the two (adopters and this counterfactual of non-adopters), we can get the impact of the technology on the adopters. Though, the adopters and comparison groups may differ in unobservable characteristics, if they are matched in terms of observable characteristics, Baker (2000) argues that selection on unobservable characteristics is empirically less important in accounting for evaluation bias.

[27] For an elaborate exposition of the empirical strategy of Propensity Score Matching, refer to chapter three. Since the principals remain the same, the study couldn't repeat the strategy here for avoidance of notation clutter.

Also in a situation where the same questionnaire is administered to both groups (so that outcomes and personal characteristics are measured in the same way for both groups) and the participants and controls are placed in a common economic environment (such as the case in this study), matching substantially reduces bias (Heckman et al., 1998). The main steps involved in the application of statistical matching to impact evaluation are: estimating the propensity scores of the adopters and non-adopters using probit regression analysis, matching the propensity scores between the adopters and non-adopters using nearest neighbor, kernel, radius and stratification options, assessing the quality of the matches and estimating the impact and its standard error. This method is based on modeling the probability of treatment given covariates, called the probability propensity score (PPS). The matching methods thus compare the means of the treated and un-treated groups with similar propensity scores. From this study's household survey data, suppose that two farmers from the sample, and from different treatment types, have identical PPS, then under the ignorability condition, the average treatment effect, conditional on the PPS and provided it is not equal to either 0 or 1, is equal to the expected difference in the observed test scores between farmers who adopted improved certified seed and matched farmers who did not apply improved certified seed.

Econometrically, after matching, the testing of comparability of the selected groups is done and the result tested for statistical significance difference in the explanatory variables used in the probit models between the matched groups of adopters and non-adopters. Once the match (counterfactual) is of good quality, it is then used to compute the Average Treatment Effect for the Treated (ATT) to determine impact following the works of Rosenbaum and Rubin (1974).

The conditional independence assumption (CIA) under PSM is premised on the fact that once we control for a vector of observable variables X, then the decision to adopt improved certified cassava seed is random. To ensure that we observe the CIA, we test the balancing property following the standardized bias approach proposed by Rosenbaum and Rubin (1985) based on checking the differences in covariates between adopters and non-adopters before and after the procedure. Following Magrini and Vigani (2016), the study also re-estimated the propensity score on the matched sample to verify if the pseudo-R^2 after the matching is fairly low and then performed a likelihood ratio test on the joint significance of all regressors following Sianesi (2004). The Pseudo R^2 indicates the goodness of fit of the logit regression before (over the full sample) and after (only on the matched sample) the matching procedure. The p-values report the joint significance of the covariates in the logit regression before and after matching.

The sensitivity of the PSM estimates to a hidden bias was verified by testing for the presence of unobserved covariates that simultaneously affect the improved certified cassava seed adoption and the productivity and welfare outcomes. This was achieved by applying the Rosenbaum bounds test (Rosenbaum, 2002) which measures the amount of unobserved heterogeneity to be introduced in the model to challenge its results following the works of Magrini and Vigani (2016). Finally, the robustness of the PSM results is tested through sensitivity analysis by estimating the ATT using the Nearest Neighbor, Kernel and Radius matching estimation procedures.

This study focuses the analysis on the Average Treatment Effect on the Treated (TT) because it can be considered the main parameter of interest (Becker and Ichino, 2002; Magrini and Vigani, 2016). As earlier noted, for the PSM method to effectively work, the common support condition must be met. This condition requires that there are observations in the treated and un-treated groups with similar PPS who can be matched. Figure 5.4 plots the PPS for farmers who applied improved certified seed vs improved uncertified seed or local seed. The figure shows that the common support condition is met, the area below the two curves.

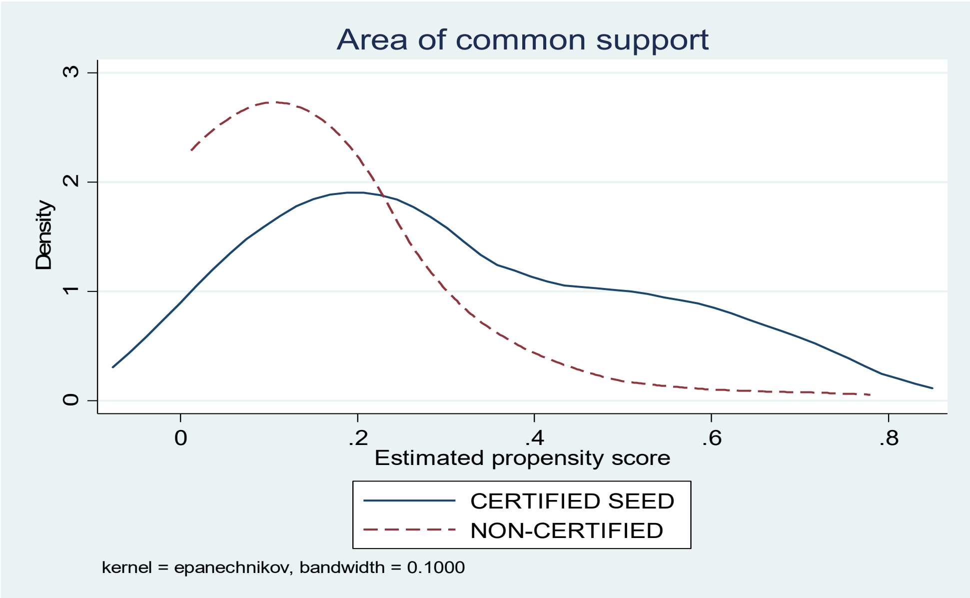

Figure 5.3: Area of common support for improved certified seed Vs improved uncertified or local seed use
***Source*: Own data**

5.12.2 Empirical results and discussion on the impact of improved certified seed use using PSM

Results from the PSM estimation are presented in Table 5.5 below.

Table 5.5: PSM Productivity and Welfare effects of cassava technology adoption

	Outcome Variables			
	Stem Yield	*Root Yield*	*HH Cons. Expenditure Per Capita '000 UGX)*	*HH Per Cap Cassava Income ('000 UGX)*
	1	**2**	**3**	**4**
Average Treatment Effect on the Treated (ATT)	10.545**	-146.368	0.669**	0.155 **
t-statistic	(1.991)	(-0.364)	(1.676)	(1.724)
Number of farmers using certified seed (Treated)	117	117	117	117
Number of farmers not using certified seed (Control)	80	64	80	80

Standard errors are computed using bootstrapping. t-statistics in parentheses; * p<0.1 is significance at 10%; , ** p<0.05 is significance at 5%; and *** p<0.01 is significance at 1%

Since 1 hectare =2.47 acres, then 10.545 stem bags/acre=26.046 stem bags/ha

Table 5.5 presents the Propensity Score Matching (PSM) results of the productivity and welfare effects of improved certified cassava seed adoption. The results are computed using nearest neighbor matching. Consistent with OLS results, the use of improved certified seed increases cassava stem yield. The farmers who applied improved certified seed harvested about 11 bags of cassava stem, high above those who applied improved uncertified or local seed, and the difference is positive and statistically significant.

Results also indicate that use of improved certified cassava seed is welfare improving. For instance, households who used improved certified seed spent 67% more than they would have spent had they used improved uncertified or local seed and the difference is statistically significant at 5% level. In addition, households who used improved certified seed earned 15.5% more cash income from cassava than they would have earned had they used improved uncertified or local seed and the difference is statistically significant at 5% level. The results are robust to other matching methods such as kernel and radius matching. This is in agreement with previous studies (Kassie et al., 2011, Amare et al., 2012; Asfaw, 2012 a&b; Kuntanshula and Mungatana, 2013; Shiferaw et al., 2014; Wellard et al., 2015; Magrini and Vigani 2016) who reported that agricultural technology adoption increases productivity and welfare.

In the next section, the study complements the non-parametric estimation procedure (PSM) with a parametric technique called Endogenous Switching Regression model (ESR) as a way of robustness refinement.

5.13 Impact of improved certified seed adoption on household productivity and welfare using ESR modeling

5.13.1 Introduction

The use of Propensity Score Matching (PSM) helps to control for observable characteristics but cannot control for unobservable drivers, which may influence both the technology adoption, cassava stem and root yield, and household welfare indicators of cassava cash income and consumption expenditure. To address this bias, the study adopts the Endogenous Switching Regression (ESR) modeling framework. The model is a two step-procedure where, in the first stage, technology adoption is estimated using a probit model while, in the second stage, the impact of the treatment on the outcome is estimated through ordinary least squares with a selectivity correction.

The Average Treatment Effect on the Treated (ATT) are calculated by comparing the predicted values of the outcomes of adopters and non-adopters in observed and counterfactual scenarios (Shiferaw et al., 2014). The next sub-section presents an elaborate exposition of the empirical strategy of Endogenous Switching Regression model. In this study, selection of instruments during model identification and specification were aided by procedures followed in Asfaw et al. (2012a); Shiferaw et al. (2014); Khonje et al. (2015) and Magrini and Vigani, (2016). The suitability of the chosen instruments was diagnosed using falsification tests proposed in Di Falco et al. (2011); and Magrini and Vigani (2016) to confirm their joint significance. The movestay routine proposed by Lokshin and Sajaia (2004) was implemented in STATA 13 to predict and compute productivity and welfare outcomes of improved and certified cassava seed adoption.

5.13.2 Empirical strategy of the ESR model framework

As earlier stated, matching strategies only control for heterogeneity effects due to observable covariates. To account for endogeneity bias and the effects of unobservable covariates, this study employed endogenous switching regression techniques following the works of Madada and Nelson (1975), Asfaw (2010), Madola et al. (2011); Asfaw (2012a&b), Kuntansula & Mungatana (2013), Mmbando et al. (2014), Kassie et al. (2015) and Magrini and Vigani (2016). The study specifies the model for technology adoption following Loksin and Sajaia (2004). This model is comprised of the selection equation or the criterion function and two continuous regressions that describe the behavior of the farmer as he faces the two regimes of adopting the cassava technologies or not.

According to Magrini and Vigani (2016), the selection equation (E5.9) which establishes the regime of the household and two equations describing productivity or welfare outcomes for the adopters (E5.10a) and non-adopters (E5.10b) is defined as:

$$T_i^* = \beta X_i + \mu_i \qquad \text{(E5.9)}$$

$$Y_{1i} = \alpha_1 C_{1i} + e_{1i} \quad \text{if} \quad T_i = 1 \qquad \text{(E5.10a)}$$

$$Y_{0i} = \alpha_0 C_{0i} + e_{0i} \quad \text{if} \quad T_i = 0 \qquad \text{(E5.10b)}$$

where T_i^* is the unobservable latent variable defining the technology adoption regime, T_i its observable counterpart and X_i the vector of covariates determining adoption. Y_i refers to the productivity or welfare outcome in regime 1 (adopters) and 0 (non-adopters), while the set of covariates C are their determinants. The error terms μ_i, e_{1i}, and e_{0i} are assumed to have a trivariate normal distribution with zero mean and a covariance matrix:

$$\begin{pmatrix} \sigma_{e1}^2 & . & \sigma_{e1u} \\ . & \sigma_{e0}^2 & \sigma_{e0u} \\ . & . & \sigma_u^2 \end{pmatrix} \qquad \text{(E5.11)}$$

According to Asfaw (2010), since σ_{e1u} and σ_{e0u} are different from zero, the expected values of the error terms of the productivity or welfare outcomes are non-zero and equal to: $E[e_{1i}|T_i = 1] = \sigma_{e1u} \frac{\phi(\beta X_i)}{\Phi(\beta X_i)} = \sigma_{e1u}\lambda_{1i}$ (E5.12a)

$$E[e_{0i}|T_i = 0] = \sigma_{e0u} \frac{\phi(\beta X_i)}{1-\Phi(\beta X_i)} = \sigma_{e0u}\lambda_{0i} \qquad \text{(E5.12b)}$$

Where $\phi(.)$ and $\Phi(.)$ indicate, respectively, the standard normal density and standard normal cumulative functions. If the estimated covariates σ_{e1u}' and σ_{e0u}' turn out to be statistically significant, then the decision to adopt improved certified cassava seed is correlated with the productivity or welfare outcomes, implying that there is evidence of endogenous switching and the presence of sample selection bias (Maddala and Nelson, 1975; Loskin and Sajaia, 2004; Di Falco et al., 2011; Magrini and Vigani, 2016). According to Maddala and Nelson (1975), this model is defined as the ‘switching regression model’.

The endogenous switching regression model can efficiently be estimated using the full information maximum likelihood (FIML) estimation (Lokshin and Sajaia, 2004). The FIML method simultaneously estimates the probit criterion or selection equation for improved certified cassava seed adoption and the regression equations of productivity and welfare outcomes to yield consistent standard errors. The model is identified by construction through non-linearities. As was the case in Heckman et al. (2001) and Magrini and Vigani, (2016), the results of the FILM estimation are used to calculate the average treatment effect on the treated (ATT) by comparing the expected productivity and welfare outcomes for adopters with their counterfactual scenario such that:

$$E[Y_{1i}|T_i = 1] = \alpha_1 C_{1i} + \sigma_{e1u}\lambda_{1i} \quad \text{(E5.13a)}$$

$$E[Y_{0i}|T_i = 1] = \alpha_0 C_{1i} + \sigma_{e0u}\lambda_{1i} \quad \text{(E5.13b)}$$

$$E[Y_{1i}|T_i = 1] - E[Y_{0i}|T_i = 1] = C_{1i}(\alpha_1 - \alpha_0) + \lambda_{1i}(\sigma_{e1}^2 - \sigma_{e0}^2) \quad \text{(E5.14)}$$

The FIML estimates of the parameters of the endogenous switching regression model are obtained using the STATA command '***movestay'*** proposed by Lokshin and Sajaia (2004).

5.13.3 Empirical results and discussion on the impact of improved certified seed use using ESR modeling

Table 5.6 reports the ESR model results on the expected productivity and welfare outcomes under actual (to adopt) and counterfactual conditions (not to adopt).

Table 5.6: Impact of improved certified seed adoption on household productivity and welfare using ESR modeling

	Improved Certified Seed Adoption			
	Adoption decision		Av. Treatment Effects on the Treated	
Outcome variable	***To adopt***	***Not to adopt***	**ATT**	**t-test**
Cassava Stem Yield (bags/acre)	66.68137	48.99782	17.68354 ***	7.3272
Cassava Root Yield (Kgs/acre)	7542.19	3310.74	4231.451***	13.0881
HH Cons. Expenditure Per Capita ('000 UGX)	7.425801	7.101992	0.3238089***	5.4732
HH Per Cap Cassava Income ('000 UGX)	6.127617	5.257146	0.870471***	5.3572

Standard errors are computed using bootstrapping. * p<0.1 is significance at 10%; , ** p<0.05 is significance at 5%; and *** p<0.01 is significance at 1%

Since 1 hectare =2.47 acres, then 17.68 stem bags/acre=43.68 stem bags/ha while 4231.451 Root Kgs/acre = 10,451.68 root Kgs/ha

ATT reports the average treatment effect on the treated (effect of improved certified cassava seed adoption on the adopters) calculated as in (E5.14). For consistency reasons and as was the case in PSM estimation, the study focuses the analysis on the Average Treatment Effect on the Treated (ATT) because it can be considered the main parameter of interest (Becker and Ichino, 2002; Magrini and Vigani, 2016). The outcome variables are modeled using the set of covariates that were used in OLS, and matching estimation methods. The ESR ATTs in Table 5.6 are interpretable as the mean differences between the predicted outcome variables when adopters actually adopt the technology and if they decided not to adopt. The results largely confirm the positive relationship between technology adoption and productivity and welfare, with treatment effects substantially in line with and reinforcing those reported in the PSM results Table 5.5.

Overall, the results indicate that improved certified cassava seed use is yield and welfare enhancing. The ATT productivity results indicate that farmers who applied certified seed harvested 18 more bags of cassava stem compared to what they would have harvested had they used improved uncertified or local seed. This study also reveals that farmers who adopted improved certified cassava seed harvested 4,231 Kgs/acre more than they would have harvested had they used uncertified seed or local seed. This is in agreement with Kassie et al. (2012), Shiferaw et al. (2014), Kassie et al. (2015), and Magrini and Vigani (2016) who observed that improved seeds can improve crops' productivity allowing for higher production quantities both for self-consumption and for increased household income.

In conformity with the Uganda national statistics, the results indicate that farmers who adopted improved certified cassava seed harvested 7,542.19 Kgs/acre (18,629.20 Kgs/ha or 18.6 tones/ha) which lies between the national figure of 7-12 tones/ha for on- farm root yield and 25-35 tones/ha for on-research station root yield (NARO, 2014; UBOS, 2016; FAO, 2016).

While the on-farm improved cassava root yield statistics are 8-15 tones/ha, this study's results revealed 18.6 tones/ha indicating an improvement of 7.1 tones/ha which can be attributed to seed inspection and certification. Relatedly, while the on-research station improved cassava yield statistics are 25-35 tones/ha, this study's results revealed 18.6 tones/ha indicating a narrowed yield gap of 6.4 tones/ha. The yield gap implies that farmers adopting improved certified cassava varieties need to do more in terms of agronomic practices. It may be possible that soil fertility occasioned the registered yield gap and therefore policy interventions in terms of fertilizer support programmes are advised. It is noteworthy that the root yield findings of this study are in agreement with the national statistics which lends credence to the reliability of the root yield data that was collected.

With regard to welfare, farmers using improved certified seed spent on household consumption goods 32.3% more than they would have spent had they used improved uncertified or local seed and the difference is statistically significant at 1% level. In addition, farmers who used improved certified seed earned 87% more cash income from cassava than they would have earned had they used improved uncertified or local seed and the difference is statistically significant at 1% level. In agreement with Bezu et al. (2014), Shiferaw et al. (2014), Kassie et al. (2015), and Khonje et al. (2015), this study's results suggest that technology adoption, through increasing productivity, enhances welfare.

The considerable impact of improved certified cassava seed on stem and root yields as well as on the welfare indicators of cassava cash income and consumption expenditure suggests that the policies undertaken in the past by the Government of Uganda at national level for the diffusion of cassava technologies, such as intensification of seed inspection and certification services by the agriculture ministry and promotion of Cassava Seed Entrepreneurs go in the right direction with respect to the goal of increasing cassava productivity and household welfare and letting the cassava sub-sector in the country exploit its full potential. The findings of the study support Hypothesis 3, which states that the productivity and welfare outcomes of farmers using improved-certified cassava seed is higher than that of the farmers using improved-uncertified or local cassava seed.

5.14 Comparing differences in causal estimation between conventional and robust impact estimation methodologies

5.14.1 Introduction

In section 1.4 of chapter one, it was hypothesized that there is equality of outcome estimates across the different impact estimation strategies. This results' comparison is aimed at supporting the argument that it is possible to maintain a wrong hypothesis and put forth policy recommendations based on biased evidence. The results make a case for impact estimation using robust identification strategies that control for all possible bias.

Table 5.7: Differences in causal estimation between conventional and robust impact estimation methodologies

Outcome Variable	Estimation method			
	Mean[28]	OLS	NN	ESR
Stem yield (Bags/Acre)	11.207***	11***	11**	18***
Root yield (Kgs/Acre)	316.883	363	-146.4	4231.4***
PCHHConsExp'000 (UGX)	2.53**	0.0233***	0.669**	0.32***
PCHHCassIncome'000 (UGX)	5.97	0.322***	0.155 ***	0.87***

**** p<0.1 is significance at 10%; ** p<0.05 is significance at 5%; and *** p<0.01 is significance at 1%***

Contrary to what had been hypothesized, the study results show varying magnitude across the different impact estimation strategies. This is so because robust methodologies eliminate selection bias that is responsible for over and under estimation of impacts. Indeed as reported by Magrini and Vigani (2016), the difference in the magnitude of the ESR results with respect to the results obtained using matching methods should not be surprising because ESR is a parametric technique which implies specific distributional assumption for the error terms. ESR also controls for bias due to observable and unobservable covariates and thus has higher validity and reliability. This study's results therefore support the argument that it is important to estimate impact using robust identification strategies (Kuntansula & Mungatana, 2013).

The study results have revealed that analyzing root yield estimates using less robust methodologies could lead to dismissal of the positive impact of cassava technology adoption. This is so because unlike mean comparison, OLS and PSM all of which suffer bias due to confounding factors, ESR results on root yield (which are free from any bias due to observable and unobservable covariates) are positive and significant. This highlights the importance of using robust estimation methodologies in impact assessment so as to circumvent the possibility of mis-hypothesing and mis-advising policy (Kuntansula & Mungatana, 2013).

Another important factor that comes to light is the importance of assessing technology adoption impact on more than one outcome variable (Magrini and Vigani, 2016). Had the study relied only on root yield even with less rigorous identification

[28] The study considered the mean difference between improved certified and improved uncertified seed use. Logs of welfare measures were taken to allow comparability with estimates from other methods.

techniques, it would have dismissed the impact of cassava technology adoption on root yield productivity. Moreover, this is more important in consideration of the fact that cassava productivity may have different meanings to different stakeholders involved in different segments of the cassava value chain. As suggested by Kuntansula & Mungatana (2013) and Magrini & Vigani (2016), measurement of productivity and welfare needs to be contextualized. While cassava stem productivity is the focus of Cassava Seed Entrepreneurs (CSE), root tuber productivity is the focus of the rest of the actors in the cassava value chain. In the same vein, cassava cash income is complemented with household consumption expenditure to broadly study welfare impacts of cassava technology adoption. This is because higher income availability favors a more diversified pattern of consumption (Pauw and Turlow, 2010).

5.15 Conclusions and policy recommendations

This chapter examined the determinants of cassava technology adoption and the effect of the adoption and adoption intensity on cassava yield and household welfare using the two-part model. The yield analysis used stem yield (bags/are) and cassava root yield (Kgs/acre) as yield indicators. On the welfare analysis front, the study used per capita cassava cash income and per capita household total consumption expenditure.

The adoption and adoption intensity determinants results show that AIP membership increased the likelihood of adopting cassava technologies. In addition, education level and extension provision were found to be major determinants of cassava technology adoption. For instance, AIP membership is associated with 30% and 70% higher likelihood of adopting improved certified seed as opposed to improved uncertified and local seed respectively. Also, the intensity of adoption is higher for AIP members compared to non-AIP members. Specifically, the area allocated to improved certified seed is 0.96 acres higher for AIP members than for non-AIP members. Also, increasing the household average schooling years by one is associated with a 6% higher likelihood of applying improved certified seed compared to improved uncertified and local seed; and an increased area allocation to improved certified cassava seed growing by 0.85 acres. Further still, households which received extension in 2015 allocate 0.71 more acres of land to improved certified seed than their counterparts that did not receive extension.

On the productivity and welfare effects of technology adoption, the study applied a series of impact estimation techniques with varying levels of rigor starting with mean comparison of outcome variables, then OLS and finally PSM and ESR. The results show that farmers who planted improved certified seed experienced higher productivity and welfare outcomes as compared to their counterparts who planted improved uncertified or local seed. For instance, ESR empirical results indicate that using improved certified cassava seed increases stem and root yield by 18 bags/acre (43.68 bags/ha) and 4.2 tones/acre (10.45 tones/ha) respectively while at the same time increases household total consumption expenditure and cassava cash income by 32% and 87% respectively. These findings were consistent across the different estimation methods.

The results indicate the role of awareness in enhancing technology adoption because all the factors related to a high likelihood of technology adoption such as AIP membership, education level, and having received extension services relate to the knowledge and awareness about the importance of technology adoption. Therefore, interventions that help farmers to appreciate the importance of technology use, the source and access can enhance its adoption. The findings establish that use of improved certified seed results in increased productivity and welfare outcomes. The findings lend credence and support to the World Bank Global Monitoring Report (2016) which posits that incomes and welfare require productivity growth in agriculture possibly through the use of improved seeds, fertilizer, pesticides, and irrigation; and diversification to other more remunerative forms of employment. This requires addressing the challenge of low quality agricultural inputs and constraints (such as credit, extension, and access to markets) that some farmers face.

This study deliberately used the two main cassava yield parameters (stem and root yield) for productivity; and cassava cash income and household consumption expenditure for welfare so as to broaden policy intervention target points. For instance, from a policy advice perspective, the results would suggest that breeding programs shouldn’t focus on root tuber yield only but also stem yield. The research findings did indicate that stems are as much of an income source to cassava farmers as root tubers.

When ESR, an impact estimation technique that is free from bias caused by both observable and unobservable confounding factors was applied, the study obtains positive and significant results on all parameters of study contrary to the findings obtained from less robust estimation methodologies. This confirms the importance of using robust impact estimation methodologies that utilize the counterfactual outcomes framework to circumvent biases stemming from non-experimental observational data. On account of the research findings, the study therefore attains the requisite confidence to recommend that policy interventions should always be based on evidence generated through the most robust statistical methodologies.

Finally, the study was able to show that use of improved certified seed leads to better productivity and welfare outcomes as compared to use of improved uncertified seed. Based on this, evidence was generated to support government policies aimed at increasing and sustaining public investments in variety genetic improvement, seed inspection and certification.

5.16 Contribution to knowledge and literature

One of the major contributions to literature is that the study has been able to circumvent the inadequacies identified in the multitude of previous studies done on impact estimation of agricultural technology adoption. These inadequacies include, inter alia: (a) assessing the effects of single technologies (usually only seed genetic improvement), disregarding the impact of other important complimentary innovations such as seed certification; (b) evaluating the impact of agricultural technologies using sub-national location specific datasets at district or regional level thereby disregarding nationally representative datasets; (c) limiting the analysis to a single measure of productivity (usually grain yield) or welfare (incomes or consumption expenditure) disregarding the fact that both productivity and welfare are multi-dimensional and complex phenomena which cannot be understood through single indicators; and (d) estimating impact of technology adoption using less rigorous estimation methodologies that lack frontier robustness checks.

Based on the above exposition, it is contended that the study has successfully contributed to the literature on impact of agricultural technology adoption by empirically estimating the impact of cassava technology adoption on productivity and welfare in Uganda. Indeed the study has successfully constructed an empirical bridge between the largely neglected cassava commodity and the adoption impact evaluation literature. To achieve this, the study focused its analysis on more than one measure of productivity and welfare by including both cassava stem and root yield (as productivity measures) and cassava cash income and household consumption expenditure (as complementary welfare measures). In doing so, the study used a nationally representative household and plot level cross-sectional survey dataset of 609 households distributed all over the major cassava growing regions of the country and thereby going beyond the usual approach of investigating local case studies, which are not sufficiently informative for the implementation of policies at national level. This approach allowed us to include several policy-relevant variables that were not included in previous studies.

In order to circumvent the methodological challenges identified in the reviewed studies, this study, beyond empirically determining what causes farmers to source cassava seed from certain seed sources and not others, closely approximated proper randomization procedures through matching (Propensity Score Matching) and endogenous switching regression modeling in estimating the productivity and welfare effects of cassava technology adoption in all the major cassava growing communities of Uganda. The robust impact estimation complementary methodologies adopted for this study (PSM and ESR) control for selection and endogeneity bias caused by observable and unobservable factors such as differences in motivation levels and management skills between adopters and non-adopters thereby creating a quasi-experimental design in estimating the impact of cassava technology adoption.

Moreover, this study makes an attempt to apply robust methodologies on cassava, a crop that has been largely shunned by most impact evaluations because of its data challenges. In consideration of its enormous importance both as a food security and industrial commercial commodity, the study argues that it is paramount to estimate the productivity and welfare impacts of cassava technology adoption.

This is particularly important to guide agricultural policy making for resource poor cassava farming communities that constitute about 75% of the country's population.

Previous studies reviewed have simply differentiated agricultural improved varieties and local varieties without giving due consideration to the eminent problem that some farmers may not clearly know which varieties they are growing (correct variety identification by farmers). Farmers may mistake improved varieties for local traditional varieties if they have grown them for quite a number of years and may also mistake traditional local varieties for modern improved varieties if they have just received the seed. It is therefore an established fact that besides soil fertility, area and yield estimation, one other major challenge in agricultural data collection is the inability of farmers to correctly identify varieties. To circumvent this potential source of error, researchers are proposing DNA indexing of sample collections done during surveys. However, this study recognizes the cost implications of sample collection and DNA indexing to correctly ascertain the varieties being grown by farmers during a survey of socio-economic nature like this one. The study therefore opted to increase variety identification accuracy by further asking farmers to recall the main source of the seed they planted. This way, it was possible to classify seed according to source. In the analysis, the study aimed at estimating the impact of adoption of cassava seed majorly sourced from government institutions (NARO and NAADS), and certified CSEs – all of which are improved seed sources that have seed inspection and certification services embedded. The study applied the robust Propensity Score Matching (PSM) and Endogenous Switching Regression Modelling (ESRM) impact estimation techniques to estimate the productivity and welfare impact of improved-certified cassava seed adoption using improved-uncertified or local seed as the reference categories. To the best of my knowledge, this is one of the first studies that has successfully attempted this novel approach of reducing farmer error of variety identification in relation to the cassava commodity in Uganda.

While most studies conveniently apply impact estimation methods singly, this study has successfully demonstrated that evidence from triangulation of results estimated using a range of complimentary methodologies has heightened validity, reliability and policy relevancy. The study achieved this by applying a complementary combination of parametric and non-parametric econometric techniques to mitigate biases stemming from both observed and unobserved heterogeneity and to test robustness of results across methods. The parametric approach involved estimating endogenous switching regression treatment effects while the non-parametric method involved application of binary propensity score matching estimators.

Finally, using cassava data collected with tools standardized with LSMS-ISA makes it possible to compare findings of this study with other national and regional level findings arrived at through the LSMS-ISA panel surveys. Allowing broader comparability of study findings increased validity and reliability of this study's findings and their corresponding policy recommendations.

5.17 Study limitations and suggestions for further research

1. Besides soil fertility, area and yield estimation, one other major challenge in agricultural data collection is the inability of farmers to correctly identify varieties. Most farmers lack full capability to distinguish between improved and local varieties especially when they have grown them for quite a number of years such that they confuse improved varieties with local varieties. To circumvent this potential source of error, researchers should use DNA indexing following sample collections done during surveys. While this may have cost implications, it is proposed as a novel approach to correctly distinguish between improved and local varieties during socio-economic data surveys. In suggesting this, it is argued that science should complement socioeconomics in improving research results reliability.

2. Cassava root yield as a measure of productivity consistently showed insufficient or no statistical significance at all in some of the estimations. The statistical behavioral consistency points to systemic data measurement issues in self-reported cassava root production data. This happened despite the fact that this study tried the best it could to accurately capture root yield data from the respondent farmers using repeated recall rigour, visualization, and real time plot root harvest farmer reported estimations. The challenge remains, especially for Sub-saharan Africa (SSA) where farmers rarely keep records and where cassava, being a major food security crop, is continuously harvested in piece-meal[29] making it difficult to accurately know the exact

[29] Piece-meal harvest means harvesting in small bits required for the day's meal as opposed to harvesting at once

quantities harvested from a particular area. To circumvent this inherent root yield data capture challenge, it is suggested that future research should consider undertaking physical harvest of cassava from a measured-off garden area and then approximate to the entire garden area. As suggested by Gourlay et al. (2017); this is called crop cutting which involves harvesting a small part of the field (usually 4x4 meters) and then weighing that harvest.

3. There is sufficient evidence in literature (Carletto et al., 2013; Ali and Deininger, 2015; Carletto et al., 2015; Carletto et al., 2016; Gourlay et al., 2017; Bevis and Barrett, 2017; Desiere and Jolliffe, 2017; Kilic et al., 2017) that small-holder farmers tend to over-report plot size relative to medium-sized land-holders, while the largest farm groups under-report plot size on average. This is corroborated with earlier evidence from Mali reported by De Groote and Traorè (2005). The same authors variously also argue that the more farmers overestimate the size of their field (relative to GPS measured size), the more inputs they seem to use. Conversely, when they underestimate the size of their field, they use less. This may also lead to farmers over or under estimating their yields. While self-reported land size measures have for a long time been the only option available to practically collect data on the physical dimension of the plots owned or cultivated by the household; Carletto et al., 2016; Gourlay et al., 2017; Kilic et al., 2017) argue that they (self-reported land measures) are notoriously imprecise. In agreement with literature, this study supports the position that accurate measurement of land is of outmost importance in economies that are largely agricultural based and for communities that derive a large share of their livelihood from agriculture and for whom land constitutes the main, when not the only, capital asset. In particular, an accurate measure of land size is necessary if one is to measure agricultural productivity with any degree of validity. GPS technologies clearly hold promise for improving the accuracy in the collection of land size measures in the context of large household surveys. The continuing fall in the price and increasing precision and reliability of GPS devices makes them an increasingly essential element of every survey team toolkit and that future socio-economic survey designs should cover the hire or purchase of GPS machines.

4. Food security remains paramount in SSA owing to the increasing population and declining soil and crop productivity occasioned in part by the changing climate (FAO, 2015a, b). This study has used self-reported measures of food insecurity and moreover with analysis ending at the descriptive stage. This study also used self-perception variables which may potentially suffer endogeneity concerns. While self-reported food security measures have the advantage of cost-effectiveness, Kabunga et al. (2014) argue that subjective indicators run a risk of reporting a biased perception of a households' own status, and they do not provide information on food utilization, such as calorie intake, intra household food preparation and distribution. Accordingly, it would be important to empirically assess the impact of cassava innovations on food security using all the four pillars of food security: food availability, access, utilization, and stability. As argued in Magrini and Vigani (2016), these four pillars must be simultaneously met to ensure that all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life.

5. Finally, the study suggests as an area for further research, an empirical study on the differences between stem and tuber sales contribution to household income. This would guide policy interventions required for the support of the different segments of the cassava value chain.

6 CHAPTER SIX: THESIS CONCLUSIONS, POLICY RECOMMENDATIONS, CONTRIBUTION TO KNOWLEDGE, STUDY LIMITATIONS AND SUGGESTIONS FOR FURTHER RESEARCH

6.1 Chapter overview

In this study, agricultural innovations included: improved cassava varieties (cassava seed genetic improvement), certified seed of improved cassava varieties (cassava seed inspection and certification), cassava seed delivery systems (seed sources) and an Agricultural Innovation Systems approach to technology generation, promotion and utilization (AIS initiatives). In Uganda, agricultural technology generation, promotion and utilization is moving towards Agricultural Innovation Systems (AIS) approaches with the adoption of elements of AIS such as involvement of multiple stakeholders. Farming households may choose to either participate in the AIS initiatives through membership to Agricultural Innovation Platforms (AIPs) or not. Either way, whether they belong to AIPs or not, they are able to access and utilize, if they choose to, agricultural innovations. Some households choose to adopt the innovations under promotion while others choose to remain using the traditional options. The use or non-use of these innovations translates into varying productivity and welfare outcomes.

Based on this study conceptualization, an extensive review of literature was carried out to crystallize and problematize the research gap which led to identification of the 7 research questions: (a) what are the causal determinants of participation in Agricultural Innovation System platforms? (b) what is the impact of participation in AIS interventions on cassava productivity and household welfare of cassava growing communities in rural Uganda? (c) what are the causal factors influencing the choice of cassava seed access sources? (d) what are the determinants of cassava technology adoption? (e) what is the impact of improved-uncertified cassava seed adoption on household productivity and welfare? (f) what is the impact of improved-certified cassava seed adoption on household productivity and welfare? (g) do different impact estimation strategies yield the same impact estimates?

To answer the 7 research questions, an empirical investigation was carried out in an attempt to fulfil the objectives set for the study and to establish evidence required to test the set hypotheses. In this chapter, the study presents the 10 major conclusions and policy recommendations informed by the evidence generated through answering the 7 research questions of the study. The chapter also presents an articulation of what is contended to be the 7 contributions to the existing body of organized knowledge in the areas studied. The chapter concludes with a submission of the identified 7 study limitations and suggestions for further research.

6.2 Thesis conclusions and policy recommendations

First, through this study, it has been established that households who received extension services prior to AIS initiative commencement were more likely to join AIPs. In addition, highly educated households and those that belong to other groups were more likely to join AIPs than their less educated counterparts and those that do not belong to other groups. The analysis of the impact of AIP membership on productivity and welfare revealed that AIP membership positively and significantly increases cassava stem yield, per capita cassava income, and per capita consumption expenditure. It was also found out that AIP members were more likely to adopt productivity enhancing inputs such as the use of improved certified seed. These findings suggest that AIP membership enhances farmers' knowledge and expertise regarding better farming practices which translates into increased productivity and welfare. Any programme that enhances AIP participation deserves support in as far as it enhances technology adoption, productivity and household welfare. One major way of enhancing AIP participation is through awareness creation using other existing programs such as extension services and farmer group memberships. Government should specifically target and invest in popularizing AIPs.

Second, overall, the considerable impact of AIS participation on stem and root yields as well as on the welfare indicators of cassava cash income and consumption expenditure suggests that the development plans, programmes and projects undertaken in the past by both the state and non-state actors at national and regional levels for the promotion and diffusion of cassava technologies through Multi Stakeholder Innovation Platforms (MSIPs) or rather Agricultural Innovation Platforms (AIPs) were successful. To the extent that Agricultural Innovation Systems concepts such as intensification of seed inspection and certification services by the agriculture ministry and promotion of Cassava Seed Entrepreneurship were applied in the cassava technology generation, promotion and utilization leading to better livelihood outcomes, this study recommends that, AIS as an IAR4D approach, should be promoted sustainably with commensurate budgetary allocations through the national research and extension systems.

Third, on another inquiry thrust, the study examined the characteristics of farmers who source cassava seed from certified and uncertified sources, and then applied a probit model to study the determinants of seed source choice. The results indicate that farmer perceptions about the use of modern seed, household decision-making (whether the husband decides alone or husband and wife jointly decide), input access shocks and the perceptions about the seed access sources play an important role in influencing farmers choice of a given seed access source. With those findings, the study recommends that farmer development programmes and project initiatives should deliberately encourage households to discuss and make decisions jointly as opposed to individual decision-making which in most cases is flawed from limited information and lack of family cooperation. In line with this, women empowerment should be treated as critical in as far as it facilitates informed joint decision-making necessary to meet multiple objectives in the households.

Fourth, deliberate efforts aimed at changing farmer perceptions about seed access sources should be promoted by government extension and non-state farmer empowerment programmes. This can be achieved through targeted farmer training and extension services. Agricultural technology promotion should be carried out using Agricultural Innovation Systems (AIS) approaches so as to attain higher impact on farmers' attitudes. With the right information and guidance, farmers are able to make informed decisions and choices resulting in better agricultural practices and consequently better productivity and welfare outcomes.

Fifth, it is further advised that increasing availability and access to improved certified seed should be a targeted and perhaps shared venture. Both state and non-state actors should fund decentralized cassava seed multiplication centers across farming communities. These seed multiplication centers should be inspected and certified according to proven and approved scientific and regulatory protocols. This together with a functional government extension system aimed at providing information necessary to make informed decisions and illuminating the benefits of using improved certified seed would yield better farming outcomes. Through subsidized arrangements, farmers can be incentivized through the Operation Wealth Creation (OWC) national programme to access, at affordable premiums, seed from these multiplication centers or through certified Cassava Seed Entrepreneurs. The latter would then buy certified seed from the multiplication centers described above. This seed would then be further multiplied for sale to sensitized farmers who would, through effective extension services, be able and willing to buy.

Sixth, the determinants of cassava technology adoption and the effect of the adoption and adoption intensity on cassava yield and household welfare were examined using the two-part model. The yield analysis used stem yield (bags/are) and cassava root yield (Kgs/acre) as yield indicators. On the welfare analysis front, the study used per capita cassava cash income and per capita household total consumption expenditure (adjusted by Adult Equivalent Units). The adoption and adoption intensity determinants results show that AIP membership increased the likelihood of adopting cassava technologies. In addition, education level and extension provision were found to be major determinants of cassava technology adoption.

Seventh, on the productivity and welfare effects of technology adoption, the study applied a series of impact estimation techniques with varying levels of rigor starting with mean comparison of outcome variables, then Ordinary Least Squares (OLS) and finally Propensity Score Matching (PSM) complimented with Endogenous Switching Regression (ESR) modeling. Study results show that farmers who planted improved certified cassava seed experienced higher productivity and welfare outcomes as compared to their counterparts who planted improved uncertified or local seed. These findings were consistent across the different estimation methods.

The results indicate the significant role of awareness in enhancing technology adoption because all the factors related to a high likelihood of technology adoption such as AIP membership, education level, and having received extension services relate to the knowledge and awareness about the importance of technology adoption. Therefore, interventions that help farmers to appreciate the importance of technology use, the source and access can enhance its adoption. The study findings also established that the use of improved certified seed results in increased productivity and welfare outcomes. The findings lend credence and support to the World Bank Global Monitoring Report (2016) which posits that incomes and welfare require productivity growth in agriculture possibly through the use of improved seeds among others. This requires addressing the challenge of low quality agricultural inputs and constraints such as access to affordable agricultural financing, extension, and access to markets that some farmers face.

Eighth, this study deliberately used the two main cassava yield parameters (stem and root yield) for productivity; and cassava cash income and household consumption expenditure for welfare so as to broaden policy intervention target points. For instance, from a policy advice perspective, the results suggest that breeding programs should not focus on root tuber yield only but also stem yield. The research findings did indicate that stems are as much of an income source to cassava farmers as root tubers. In agreement with literature (Magrini and Vigani 2016), productivity and welfare are a multidimensional complex phenomena that cannot be comprehensively studied through single measures. Moreover, productivity and welfare may mean different things to different actors and therefore the need to study the two using more than one indicator and to focus on various segments of the value chain.

Ninth, when ESR, an impact estimation technique that controls for much of the bias caused by both observable and unobservable confounding factors, was applied, positive and significant results were obtained on all parameters of study contrary to the findings obtained from less robust estimation methodologies. This confirms the importance of using robust impact estimation methodologies that utilize the counterfactual outcomes framework to circumvent biases stemming from non-experimental observational data. On account of the research findings, this study therefore gathers the requisite confidence to recommend that policy interventions should always be based on evidence generated through the most robust statistical methodologies.

Tenth and finally, this study was able to show that use of improved certified seed leads to better productivity and welfare outcomes as compared to use of improved uncertified seed. Based on this, evidence was generated to support government policies aimed at increasing and sustaining public investments in variety genetic improvement, seed inspection and certification. It is therefore recommended that both state and non-state actors should continue to sustainably invest in and promote decentralized seed inspection and certification programmes so that even the remotely located individual smallholder and resource constrained farmers can benefit from the service.

6.3 Contributions to knowledge and literature

From the foregoing evidence, it is contended that this study has successfully added new knowledge to the existing body of organized knowledge on impact assessment of agricultural technology/innovation adoption in the following seven ways.

First, to the best of my knowledge, this is the first attempt to identify and characterize cassava AIS initiatives in Uganda (CRCoE and CSE) which have both been implemented with reference to AIS concepts including Multi-stakeholder Innovation Platforms herein called Agricultural Innovation Platforms (AIPs). This is the first study to empirically examine the determinants of household participation in the characterized AIS initiatives in Uganda. Moreover the probit model used a richer set of variables including institutional factors, farmer perceptions, decision-making, wealth and asset variables including TLUs to explain determinates of household participation in the characterized AIS initiatives. Further still, in the analysis for both the causal determinants of household participation in AIS initiatives and impact of AIS participation, this study used pre-intervention (2010) data to mitigate challenges of reverse causality. To the best of my knowledge, this is one of the first studies in recent years to empirically study cassava AIS participation impacts on cassava productivity and welfare in Uganda using robust identification methodologies. To the extent that this study's findings are more robust and more amenable to policy advice, it can be concluded that the inquiry has successfully contributed to the literature on Agricultural Innovation Systems.

Second, none of the studies reviewed employed rigorous identification strategies (in estimating the impact of AIS initiatives on household livelihood outcomes) except Mapila et al. (2012) who used PSM to study ERI AIS farmer participation impacts in Malawi. Even so, Mapila et al. (2012) never comprehensively studied productivity and welfare impacts since they stopped at incomes only. This study did so using cassava stem and root yield and per capita household consumption expenditure normalized using the more accurate Adult Equivalent Units (AEUs) and not the erroneous family size that is commonly used in most previous studies reviewed.

Third, while most previous studies conveniently choose to use per capita income as a proxy for welfare, this study complemented income with per capita household consumption expenditure which is by far a better welfare proxy or welfare outcome indicator. This is because consumption expenditure is less prone to measurement error than income.

Fourth, on another front and again to the best of my knowledge, this is the first attempt to characterize and classify cassava seed sources into certified and uncertified sources in the cassava farming sub-system of Uganda. This is the first study to empirically examine the causal determinants of farmers' choice of cassava seed sources in Uganda. Moreover the probit model used a richer set of variables including institutional factors, farmer perceptions, decision-making, wealth and asset variables including TLUs to explain causal determinants of farmers' choice of cassava seed sources. In the causal determinants analysis, the study used pre-intervention (2010) data to mitigate reverse causality challenges. The findings provide one of the first sets of empirical evidence to support seed inspection and certification programmes in Uganda; spousal roles in household cassava production decision-making as well as use of AIS concepts in technology promotion.

Fifth and perhaps another major contribution to literature is that the study has been able to circumvent the inadequacies identified in the multitude of previous studies done on estimation of impact of agricultural technology adoption. These inadequacies include, inter alia: (a) assessing the effects of single technologies (usually only seed genetic improvement), disregarding the impact of other important complementary innovations such as seed certification; (b) evaluating the impact of agricultural technologies using sub-national location specific datasets at district or regional levels thereby disregarding nationally representative datasets; (c) limiting the analysis to a single measure of productivity (usually grain yield) or welfare (incomes or consumption expenditure) disregarding the fact that both productivity and welfare are multi-dimensional and complex phenomena which cannot be understood through single indicators; (d) estimating impact of technology adoption using less rigorous estimation methodologies that lack frontier robustness checks; (e) shunning root crops especially cassava whose piece meal harvesting regimes occasion enormous yield data challenges and instead conveniently over-studying grain crops whose data challenges are limited.

Based on the above exposition, it can be concluded that this study has successfully contributed to the literature on impact of agricultural technology adoption by empirically estimating the impact of cassava technology adoption on productivity and welfare in Uganda. Indeed the study has successfully constructed an empirical bridge between the largely neglected cassava commodity and the adoption impact evaluation literature. To achieve this, the study focused the analysis on more than one measure of productivity and welfare by including both cassava stem and root yield (as productivity measures) and cassava cash income and household total consumption expenditure (as complimentary welfare measures). In doing so, this study used a nationally representative household and plot level cross-sectional survey dataset of 609 households distributed all over the major cassava growing regions of the country and thereby going beyond the usual approach of investigating local case studies, which are not sufficiently informative for the implementation of policies at national level. This approach allowed the study to include several policy-relevant variables that were not included in previous studies.

This study closely approximated proper randomization procedures through Propensity Score Matching (PSM) and Endogenous Switching Regression (ESR) modeling in estimating the productivity and welfare effects of cassava technology adoption in all the major cassava growing communities of Uganda. The robust impact estimation complementary methodologies adopted for this study (PSM and ESR) control for selection and endogeneity bias caused by observable and unobservable factors such as differences in motivation levels and management skills between adopters and non-adopters thereby creating a quasi-experimental design in estimating the impact of cassava technology adoption.

Sixth, previous studies reviewed have simply differentiated agricultural improved varieties and local varieties without giving due consideration to the eminent problem that some farmers may not clearly know which varieties they are growing (correct variety identification by farmers). Farmers often mistake improved varieties for local traditional varieties if they have grown them for quite a number of years and may also mistake traditional local varieties for modern improved varieties if they have just accessed the seed. It is therefore an established fact that besides soil fertility, area and yield estimation, one other major challenge in agricultural data collection is the inability of farmers to correctly identify varieties. To circumvent this potential source of error, researchers have proposed DNA indexing of sample collections done during surveys. However, this study recognizes the cost implications of sample collection and DNA indexing to correctly ascertain the varieties being grown by farmers during a socio-economic survey of this nature. This study therefore opted to increase variety identification accuracy by further asking farmers to recall the main source of the seed they planted. In this way, the study was able to classify seed according to source. In the analysis, this study aimed at estimating the impact of adoption of cassava seed majorly sourced from government institutions (NARO and NAADS), and certified CSEs – all of which are improved seed sources that have seed inspection and certification services embedded. The study contends that this is one of the first studies that has successfully attempted this novel approach of reducing farmer error in variety identification.

Seventh, while most studies conveniently apply impact estimation methods singly, this study has successfully demonstrated that evidence from triangulation of results estimated using a range of complimentary methodologies has heightened validity, reliability and policy relevancy. The study achieved this by applying a complimentary combination of parametric and non-parametric econometric techniques to mitigate biases stemming from both observed and unobserved heterogeneity and to test robustness of results across methods. The parametric approach involved estimating endogenous switching regression treatment effects while the non-parametric method involved application of binary propensity score matching estimators. Further still, using survey data collected with tools standardized with LSMS-ISA makes it possible to compare this study's findings with other national and regional level statistics arrived at through the LSMS-ISA panel surveys. Allowing broader comparability of study findings increased the validity and reliability of this study's findings and their corresponding policy recommendations.

Finally, this study in its entirety offers a contribution to global poverty alleviation stratagems at three levels: within the research regions whose poverty levels remain high in comparison to other country regions, within Uganda as a sovereign national entity which still ranks high among the world's Highly Indebted Poor Countries (HIPCs) and within Africa as the poorest continent on the planet despite sitting on the world's largest natural resource base. The next section outlines study limitations and suggestions for further research.

6.4 Study limitations and suggestions for further research

Learning is a lifelong process and as such no single inquiry can provide all answers in any endeavor. Accordingly, in the quest to establish answers to the seven research questions, the study identified seven potential areas for further research. In this section, succinct pointers for possible future grounds of inquiry are enumerated.

First, since this study only estimated impact of AIS participation on productivity and welfare outcomes leaving out other important livelihood outcome variables, it is advisable that further research be conducted to empirically examine the impact of AIS participation on all indicators of poverty and food security using robust estimation strategies.

Second, this study broadly categorized seed sources into certified channels (sources with inspection and certification services embedded) and uncertified sources. This led to lumping together of different seed sources. It would be interesting to study each source separately and this could be implemented using an endogenous multinomial logit regression analysis. The study suggests that an empirical inquiry be undertaken to investigate the determinants of choice of each seed source in Uganda using the proposed robust methodology.

Third, besides soil fertility, area and yield estimation, one other major challenge in agricultural data collection is the inability of farmers to correctly identify varieties. Most farmers lack full capability to distinguish between improved and local varieties especially when they have grown them for quite a number of years such that they confuse improved varieties with local varieties. To circumvent this potential source of error, researchers should use DNA indexing following sample collections done during surveys. While this may have cost implications, this study proposes it as a novel approach to correctly distinguish between improved and local varieties during socio-economic data surveys. In suggesting this, the study suggests that science should complement socioeconomics in improving research results reliability.

Fourth, cassava root yield as a measure of productivity consistently showed insufficient or no statistical significance at all in some of the estimations. This statistical misbehavioral consistency points to systemic data measurement issues in farmer-reported cassava root yield data. This happened despite the fact that this study tried the best it could to accurately capture root yield data from the respondent farmers using repeated recall rigour, visualization, and real time plot root harvest farmer reported estimations. The challenge remains, especially for Sub-Saharan Africa (SSA) where farmers rarely keep records and where cassava, being a major food security crop, is continuously harvested by piece meal making it difficult to accurately know the exact quantities harvested from a particular area. To circumvent this inherent root yield data quality challenge, it is suggested that future research should consider undertaking physical harvest of cassava from a measured-off garden portion and then approximate to the entire garden area. As suggested by Gourlay et al. (2017), this crop cutting which involves harvesting a small part of the field (usually 4x4 meters) and then weighing that harvest could provide a solution to yield data capture challenges in most SSA Africa socio-economic surveys.

Fifth, there is sufficient evidence in literature (Carletto et al., 2013; Ali and Deininger., 2015; Carletto et al., 2015; Carletto et al., 2016; Gourlay et al., 2017; Bevis and Barrett., 2017; Desiere and Jolliffe., 2017; Kilic et al., 2017) that small-holder farmers tend to over-report plot size relative to medium-sized land-holders, while the largest farm groups under-report plot size on average. This is collaborated with earlier evidence from Mali reported by De Groote and Traorè (2005). These authors variously argue that the more farmers overestimate the size of their field (relative to GPS measured size), the more inputs they seem to use. Conversely, when they underestimate the size of their field, they use less. This may also lead to farmers over or under estimating their yields. While self-reported land size measures have for a long time been the only option available to practically collect data on the physical dimension of the plots owned or cultivated by the household; Carletto et al. (2016); Gourlay et al. (2017); Kilic et al. (2017) argue that they (self-reported land measures) are notoriously imprecise. In agreement with literature, it is vouched that accurate measurement of land is of outmost importance in economies that are largely agricultural based and for communities that derive a large share of their livelihood from agriculture and for whom land constitutes the main, when not the only, capital asset. In particular, an accurate measure of land size is necessary if one is to measure agricultural productivity with any degree of validity. GPS technologies clearly hold promise for improving the accuracy in the collection of land size measures in the context of large household surveys. The continuing fall in the price and increasing precision and reliability of GPS devices makes them an increasingly essential element of every survey team toolkit and so future socio-economic survey designs should cover the hire or purchase of GPS machines.

Sixth, food security remains paramount in SSA owing to the increasing population and declining soil and crop productivity occasioned in part by the changing climate (FAO, 2015a, b). This study has used self-reported measures of food insecurity and moreover with analysis ending at the descriptive stage. While self-reported food security measures have the advantage of cost-effectiveness, Kabunga et al. (2014) argue that subjective indicators run a risk of reporting a biased perception of a households' own status, and they do not provide information on food utilization, such as calorie intake, intra household food preparation and distribution. Accordingly, it would be important to empirically assess the impact of cassava innovations on food security using all the four pillars of food security: food availability, access, utilization, and stability. As argued in Magrini and Vigani (2016), these four pillars must be simultaneously met to ensure that all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life.

Seventh and finally, this study suggests as an area for further research, an empirical study on the differences between stem and tuber sales contribution to household income. This would guide policy interventions required for the support of the different segments of the cassava value chain.

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Appendix A1.1: Stata output results for the sample size computation using power test

```
. clustersampsi, binomial detectablledifference p1(.5)  k(48) rho(.07) m(13)
Detectable difference calculation for two sample comparison of proportions (using normal appro
> ximations)
without continuity correction.


For the user specified parameters:

p1:                                                                0.50
significance level:                                                0.05
power:                                                             0.80
baseline measures adjustment (correlation):                        0.00
average cluster size:                                              13
number of clusters per arm:                                        48
coefficient of variation (of cluster sizes):                       0.00
intra cluster correlation (ICC):                                   0.0700


clustersampsi estimated parameters:


Firstly, under individual randomisation:
If, trying to detect an increasing outcome then:
detectable difference:                                             0.08
with corresponding p2:                                             0.58
If, trying to detect a decreasing outcome then:
detectable difference:                                             0.08
with corresponding p2:                                             0.42

Then, allowing for cluster randomisation:
design effect:                                                     1.84
If, trying to detect an increasing outcome then:
detectable difference:                                             0.11
with corresponding p2:                                             0.61
If, trying to detect a decreasing outcome then:
detectable difference:                                             0.11
with corresponding p2:                                             0.39
```

Appendix A3.1: Relative contribution of stem and tuber sales to total cassava cash income for AIP and Non-AIP members in Uganda Shillings (UGX)

	Pooled sample		AIP Member		Non-AIP Member	
Variable	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
PC Tuber income	675,708	4,030,440	1,967,741	7,835,408	236,473	485,264
PC Stem income	165,354	1,371,299	576,931	2,668,438	25,436	183,127
Difference	**510,354**		**1,390,810**		**211,038**	

Source: computations from own data. PC Tuber income is derived from sales of fresh tuber, dried chips, flour, cooked cassava, cassava cake, cassava bread and cassava beverage.

Appendix A5.1: Descriptive statistics of cassava farmers

VARIABLE	IMPROVED CERTIFIED	SD	IMPROVED UNCERTIFIED	SD	LOCAL	SD		t-test		t-test
Variables	Mean (A)		Mean (B)		Mean (C)		(A-B)	P-VALUE	(A-C)	P-VALUE
Productivity outcomes										
Parcel stem yield (bags/acre)	47.909	43.598	36.702	37.911	37.304	112.289	11.207***	0.012	10.605	0.312
Parcel root yield (Kgs/Acre)	3153.789	2687.352	2836.906	2380.732	2518.173	1935.591	316.883	0.311	635.616	0.935
n	**97**		**200**		**305**					
Welfare outcomes										
PCHHConsumption Exp'000 (UGX)	1451.236	1952.586	1112.275	941.1793	977.4002	611.193	338.961**	0.043	473.836***	0.000
PCHHCassIncome'000 (UGX)	1927.632	5261.337	999.2572	6734.614	383.0803	2389.575	928.375	0.229	1544.552***	0.000
Food security outcomes										
# of Meals Per Day	2.586	0.655	2.576	0.702	2.498	0.624	0.010	0.910	0.087	0.232
1 if Food deprived in 2015	0.273	0.448	0.379	0.486	0.344	0.476	-0.107**	0.068	-0.072*	0.188
# of months food insecure	0.636	1.265	0.744	1.170	0.810	1.461	-0.107	0.466	-0.173	0.290
PC HH Food Expenditure	801418.9	483952.8	698628.8	436474.7	675351.2	398619.4	102790**	0.065	126067.7***	0.010
FGT Poverty outcomes										
Head count index (% poor)	0.513		0.681		0.743		-0.168			
Poverty gap index	0.179		0.284		0.301		-0.105			
Poverty severity index	0.081		0.148		0.151		-0.067			
Decision-making										
1 if husband decides	0.616	0.489	0.527	0.500	0.534	0.500	0.089*	0.145	0.082	0.156
1 if husband and wife decide	0.212	0.411	0.261	0.440	0.210	0.408	-0.049	0.355	0.002	0.962
1 if all decide	0.020	0.141	0.030	0.170	0.030	0.170	-0.009	0.636	-0.009	0.622
1 if others decide	0.061	0.240	0.059	0.236	0.095	0.294	0.001	0.959	-0.034	0.291

Farmer perceptions										
1 if Satisified with local varietys	0.202	0.404	0.236	0.426	0.462	0.499	-0.034	0.503	-0.260***	0.000
1 if Satisified with modern varietys	0.808	0.396	0.754	0.432	0.439	0.497	0.054	0.292	0.369***	0.000
1 if Satisified with sd inspection services	0.273	0.448	0.079	0.270	0.072	0.259	0.194***	0.000	0.201***	0.000
1 if Trust Farmer cassava seed chanel	0.455	0.500	0.557	0.498	0.570	0.496	-0.102**	0.096	-0.116***	0.044
1 if Trust Govt cassava seed chanel	0.677	0.470	0.498	0.501	0.387	0.488	0.179***	0.003	0.290***	0.000
1 if Trust Govt NGO cassava seed chanel	0.424	0.497	0.315	0.466	0.203	0.403	0.109**	0.063	0.221***	0.000
1 if Trust Govt CSE cassava seed chanel	0.384	0.489	0.276	0.448	0.262	0.441	0.108**	0.057	0.122***	0.021
Seed access and farmer empowerment										
1 if Lack of improved varieties shock	0.525	0.502	0.537	0.500	0.705	0.457	-0.012	0.849	-0.180***	0.001
1 if suffered high input price shock	0.667	0.474	0.631	0.484	0.715	0.452	0.036	0.540	-0.048	0.364
1 if Labor shortage shock	0.374	0.486	0.330	0.471	0.233	0.423	0.044	0.455	0.141***	0.006
1 if Lack of mechanisation shock	0.737	0.442	0.591	0.493	0.731	0.444	0.146***	0.013	0.006	0.904
Credit access and use										
1 if Accessed credit in 2015	0.465	0.501	0.478	0.501	0.443	0.498	-0.013	0.830	0.022	0.701
Group membership										
1 if HH is a member of an AIP	0.545	0.500	0.296	0.457	0.131	0.338	0.250***	0.000	0.414***	0.000
1 if HH head belongs to a group	0.879	0.328	0.759	0.429	0.738	0.441	0.120***	0.015	0.141***	0.004
1 if Received Govt Extension in 2015	0.333	0.474	0.153	0.361	0.085	0.280	0.181***	0.000	0.248***	0.000
Social Capital/Networks										
# of people rely upon when in need	30.626	35.005	30.700	59.097	21.466	25.428	-0.073	0.991	9.161***	0.005
# of people rely free cassava seed	14.929	14.583	16.813	39.508	15.669	31.007	-1.884	0.647	-0.740	0.819
Dependence ratio	0.948	0.688	1.248	0.866	1.393	0.937	-0.300***	0.005	-0.445***	0.000
Information access										
1 if had TV	0.232	0.424	0.108	0.312	0.075	0.264	0.124***	0.004	0.157***	0.000
1 if had Radio	0.838	0.370	0.660	0.475	0.695	0.461	0.178***	0.001	0.143***	0.005
1 if had mobile phone	0.859	0.350	0.823	0.383	0.816	0.388	0.036	0.432	0.042	0.336
Transaction costs										
1 if had motor-vehicle	0.081	0.274	0.044	0.206	0.013	0.114	0.036*	0.198	0.068***	0.001
1 if had motorcycle	0.293	0.457	0.222	0.416	0.128	0.334	0.071*	0.178	0.165***	0.000
1 if Poor transport means	0.566	0.498	0.527	0.500	0.456	0.499	0.039	0.529	0.110**	0.057

Household demographics										
# of Education school years of HH head	9.847	4.627	8.450	4.350	7.483	4.399	1.397***	0.011	2.364***	0.000
Age of HH head	48.480	13.962	46.680	14.479	44.317	13.717	1.800	0.309	4.163***	0.009
Family size	7.071	2.600	7.744	3.651	6.941	2.662	-0.673*	0.102	0.130	0.672
1 if HH is female	0.141	0.350	0.138	0.346	0.213	0.410	0.003	0.935	-0.072	0.119
Land access										
HH Total land operated (Acres)	22.530	77.013	36.266	280.438	7.335	23.283	-13.736	0.633	15.195***	0.002
1 if land is owned with title	0.141	0.350	0.133	0.340	0.121	0.327	0.008	0.842	0.020	0.602
1 if land is rented in	0.121	0.328	0.054	0.227	0.062	0.242	0.067***	0.039	0.059**	0.056
1 if land was borrowed in	0.020	0.141	0.020	0.139	0.030	0.170	0.000	0.977	-0.009	0.622
Communal Land	0.010	0.101	0.020	0.139	0.020	0.139	-0.010	0.541	-0.010	0.527
Wealth status										
Tropical Livestock Units (TLUs) 2015	4.566	6.299	3.561	5.708	1.995	2.384	1.005*	0.166	2.571***	0.000
PCTotAssetValue2015	1.47E+07	3.86E+07	8975282	2.46E+07	5232620	1.11E+07	5724718	1.23E-01	9467380***	0.000
n	***99***		***203***		***305***					

**** p<0.1 is significance at 10%; ** p<0.05 is significance at 5%; and *** p<0.01 is significance at 1%***

Appendix A5.2: Relative contribution of stem and tuber sales to total cassava cash income for different seed types in Uganda Shillings (UGX)

	All Seed Types		**Improved certified**		**Improved uncertified**		**Local Seed**	
Variable	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
PC Tuber Income	675,708	4,030,440	1,261,294	3,326,046	845,572	5,874,524	372,574	2,379,425
PC Stem Income	165,354	1,371,299	666,338	2,998,354	153,685	1,049,082	10,506	115,039
Difference	**510,354**		**594,956**		**691,887**		**362,069**	

Source: computations from own data. PC Tuber income is derived from sales of fresh tuber, dried chips, flour, cooked cassava, cassava cake, cassava bread and cassava beverage.

Appendix A5.3: Determinants of adoption of improved and certified cassava seed use and adoption intensity

	Improved Vs Local		*Improved Certified Vs Uncertified & Local*		Improved Certified Vs Improv. Uncertified		Improved Certify Vs Local		Improved Uncertify Vs Local	
VARIABLES	probit	glm	probit	glm	probit	glm	probit	glm	probit	glm
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1 if AIP member	0.463***	0.838***	0.481***	0.961	0.303	0.961	0.707***	0.961	0.409**	0.379
	(3.233)	(2.932)	(3.003)	(1.539)	(1.616)	(1.539)	(3.698)	(1.539)	(2.516)	(1.470)
1 if had tarmac	0.167	0.321	0.244	0.885	0.215	0.885	0.386*	0.885	0.0811	0.0955
	(1.214)	(1.139)	(1.558)	(1.490)	(1.168)	(1.490)	(1.958)	(1.490)	(0.524)	(0.361)

HHH Education Years	0.0591***	0.0850*	0.0501**	0.202**	0.0158	0.202**	0.110***	0.202**	0.0488*	0.0136
	(2.654)	(1.916)	(1.999)	(2.185)	(0.552)	(2.185)	(3.360)	(2.185)	(1.957)	(0.328)
1 if received Extensn	0.208	0.715**	0.509***	0.250	0.458**	0.250	0.593***	0.250	0.00687	0.612**
	(1.364)	(2.310)	(2.982)	(0.382)	(2.276)	(0.382)	(2.855)	(0.382)	(0.0398)	(2.135)
1 if trained on Improved varieties	0.0191	-0.0652	-0.0973	1.078	-0.159	1.078	0.0465	1.078	0.0257	-0.275
	(0.0930)	(-0.169)	(-0.460)	(1.374)	(-0.654)	(1.374)	(0.175)	(1.374)	(0.108)	(-0.732)
1 if accessed credit	0.0319	-0.256	-0.0846	0.394	-0.138	0.394	-0.0452	0.394	0.0690	-0.474**
	(0.318)	(-1.165)	(-0.669)	(0.778)	(-0.924)	(0.778)	(-0.298)	(0.778)	(0.634)	(-2.508)
Land operated (Acres)	-0.00346**	-0.000627	-0.00362*	0.0340***	-0.00404	0.0340***	-0.00383	0.0340***	-0.00259	-0.00459
	(-1.993)	(-0.183)	(-1.647)	(2.834)	(-1.576)	(2.834)	(-1.208)	(2.834)	(-1.436)	(-1.620)
Log Asset value'000	0.0537	0.218**	0.0264	0.0768	0.00807	0.0768	0.0219	0.0768	0.0603	0.192**
	(1.156)	(2.226)	(0.457)	(0.344)	(0.124)	(0.344)	(0.308)	(0.344)	(1.166)	(2.189)
TLU 2015	0.0515***	0.0345	0.0290*	-0.0338	0.0222	-0.0338	0.0953***	-0.0338	0.0461***	0.0703**
	(3.145)	(1.100)	(1.695)	(-0.482)	(1.173)	(-0.482)	(3.362)	(-0.482)	(2.685)	(2.507)
1 if HHH is female	-0.157	-0.291	-0.0537	-0.853	0.0130	-0.853	-0.0343	-0.853	-0.205	0.163
	(-1.160)	(-0.905)	(-0.300)	(-1.132)	(0.0586)	(-1.132)	(-0.166)	(-1.132)	(-1.374)	(0.587)
Age of HH head	0.00243	-0.00622	0.00427	-0.0351*	0.00428	-0.0351*	0.00382	-0.0351*	0.00144	0.00670
	(0.628)	(-0.721)	(0.876)	(-1.799)	(0.730)	(-1.799)	(0.651)	(-1.799)	(0.342)	(0.875)
Family size	0.00496	-0.0293	-0.0374*	-0.223**	-0.0481*	-0.223**	-0.0452	-0.223**	0.0174	0.0358
	(0.282)	(-0.801)	(-1.649)	(-2.331)	(-1.903)	(-2.331)	(-1.523)	(-2.331)	(0.918)	(1.173)
High Input Cost Shock	0.212	-0.0995	0.311*	0.0794	0.265	0.0794	0.398*	0.0794	0.0978	0.107
	(1.348)	(-0.314)	(1.723)	(0.116)	(1.247)	(0.116)	(1.800)	(0.116)	(0.556)	(0.370)
1=Midwestern region	-0.154	0.208	0.168	-0.612	0.308	-0.612	0.143	-0.612	-0.198	0.167
	(-1.126)	(0.663)	(0.893)	(-0.708)	(1.419)	(-0.708)	(0.611)	(-0.708)	(-1.374)	(0.650)
1=Northern region	-0.0653	-0.349	0.610***	-1.275*	0.739***	-1.275*	0.663***	-1.275*	-0.339**	0.445*
	(-0.521)	(-1.254)	(3.899)	(-1.924)	(3.969)	(-1.924)	(3.494)	(-1.924)	(-2.402)	(1.705)
Constant	-1.234***	-1.029	-2.187***	2.771	-1.196*	2.771	-2.428***	2.771	-1.318***	-1.655**
	(-2.814)	(-1.123)	(-3.946)	(1.261)	(-1.907)	(1.261)	(-3.488)	(1.261)	(-2.720)	(-2.065)
Observations	712	712	712	712	367	367	462	462	595	595

z-statistics in parentheses; * p<0.1 is significance at 10%; , ** p<0.05 is significance at 5%; and *** p<0.01 is significance at 1%

Appendix A5.4: OLS Impact of improved and certified seed adoption on Cassava Stem and Root Yields

VARIABLES	Dependent variable is cassava stem yield (bags/acre)				Dependent Variable is cassava root yield (Kgs/acre)			
	Effect of Adoption		***Effect of adoption intensity***		***Effect of Adoption***		***Effect of adoption intensity***	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1 if used improved seed	7.177**				426.2**			
	(2.490)				(2.199)			
1 if used improved uncertified		5.776*				452.7**		
		(1.864)				(2.147)		
1 if used improved certified		10.96***				363.2		
		(2.601)				(1.313)		
Area Improved seed			-0.326				29.33	
			(-0.380)				(0.496)	
Area improved certified				0.631				-92.50
				(0.650)				(-1.479)
1 if AIP member	10.76***	10.36***	12.19***	11.56***	-144.5	-138.5	-93.79	-16.60
	(2.725)	(2.617)	(3.048)	(2.905)	(-0.555)	(-0.530)	(-0.357)	(-0.0635)
HHH Education years	0.346	0.338	0.475	0.437	1.537	1.137	9.140	14.71
	(0.561)	(0.548)	(0.767)	(0.706)	(0.0374)	(0.0276)	(0.222)	(0.358)
1 if received extension	-7.784**	-8.271**	-7.127*	-7.430*	186.1	195.1	217.2	252.9
	(-2.059)	(-2.176)	(-1.873)	(-1.954)	(0.758)	(0.788)	(0.880)	(1.028)
TLU 2015	0.747	0.714	0.895*	0.841*	-48.45	-48.09	-44.18	-36.08
	(1.621)	(1.548)	(1.926)	(1.820)	(-1.594)	(-1.580)	(-1.432)	(-1.182)
1 if own TV	2.106	1.596	2.631	2.101	519.8*	530.1*	527.4*	617.5**
	(0.446)	(0.337)	(0.550)	(0.441)	(1.682)	(1.704)	(1.675)	(1.977)
1 if HHH is female	0.957	0.906	0.564	0.740	-350.8	-352.3	-364.1	-388.4
	(0.256)	(0.243)	(0.150)	(0.197)	(-1.417)	(-1.421)	(-1.464)	(-1.563)
Age of HH head	0.000252	-0.00329	0.00317	0.00388	-3.600	-3.473	-3.243	-3.386
	(0.00239)	(-0.0311)	(0.0299)	(0.0365)	(-0.507)	(-0.488)	(-0.455)	(-0.476)
Family size	-0.586	-0.542	-0.544	-0.498	-13.68	-14.47	-9.801	-15.20
	(-1.196)	(-1.103)	(-1.106)	(-1.005)	(-0.416)	(-0.439)	(-0.297)	(-0.460)
Kms to Parcel	1.270	1.219	1.390	1.159	6.328	6.395	0.779	25.06
	(1.129)	(1.083)	(1.211)	(1.006)	(0.0851)	(0.0860)	(0.0103)	(0.332)
Land operated (Acres)	-0.0656	-0.0614	-0.0710	-0.0699	1.943	1.869	1.652	1.355
	(-1.328)	(-1.239)	(-1.430)	(-1.409)	(0.630)	(0.603)	(0.533)	(0.438)
1 if titled land	0.144	-0.319	0.201	-0.200	-27.27	-20.19	-33.59	7.650
	(0.0351)	(-0.0775)	(0.0486)	(-0.0483)	(-0.0952)	(-0.0702)	(-0.117)	(0.0265)

1 if rented in land	4.091	3.759	4.820	4.347	-192.2	-183.1	-183.1	-85.82
	(0.819)	(0.751)	(0.958)	(0.863)	(-0.555)	(-0.527)	(-0.523)	(-0.245)
1 if customary land	-1.755	-1.764	-1.794	-1.973	318.0	320.3	286.3	312.4
	(-0.586)	(-0.589)	(-0.595)	(-0.655)	(1.614)	(1.623)	(1.445)	(1.580)
Total people reliable upon	0.00351	0.00481	0.00805	0.00884	2.255	2.220	2.532	2.370
	(0.110)	(0.151)	(0.252)	(0.277)	(1.140)	(1.119)	(1.277)	(1.195)
Log asset value ‘000	-0.470	-0.477	-0.275	-0.340	-30.32	-29.43	-26.78	-20.67
	(-0.354)	(-0.359)	(-0.206)	(-0.255)	(-0.332)	(-0.322)	(-0.292)	(-0.226)
1 if accessed Credit in 2015	-0.580	-0.449	-0.539	-0.481	-251.8	-254.8	-243.3	-253.4
	(-0.211)	(-0.164)	(-0.195)	(-0.175)	(-1.376)	(-1.389)	(-1.322)	(-1.381)
1 if suffered drought shock	-2.998	-3.143	-2.565	-2.695	-500.2***	-499.3***	-471.9**	-456.4**
	(-1.047)	(-1.098)	(-0.893)	(-0.938)	(-2.628)	(-2.621)	(-2.475)	(-2.397)
1 if suffered flood shock	-4.138	-4.073	-3.574	-3.626	-124.7	-128.1	-102.7	-96.10
	(-1.062)	(-1.046)	(-0.914)	(-0.928)	(-0.469)	(-0.481)	(-0.385)	(-0.361)
1 if suffered pest-disease shock	0.318	0.377	0.852	0.778	321.0	321.2	344.9	340.3
	(0.0996)	(0.118)	(0.266)	(0.243)	(1.476)	(1.476)	(1.579)	(1.562)
1 if mid-western region	4.148	3.793	4.246	3.883	1,026***	1,031***	1,048***	1,098***
	(1.104)	(1.007)	(1.121)	(1.024)	(4.065)	(4.073)	(4.124)	(4.326)
1 if Northern region	19.00***	18.19***	18.71***	18.65***	1,782***	1,794***	1,794***	1,811***
	(5.314)	(5.003)	(5.212)	(5.195)	(7.420)	(7.369)	(7.435)	(7.524)
Constant	32.17**	32.80**	31.46**	32.36**	2,277**	2,260**	2,280**	2,173**
	(2.482)	(2.530)	(2.407)	(2.482)	(2.579)	(2.553)	(2.559)	(2.453)
Observations	693	693	693	693	564	564	564	564
R-squared	0.093	0.095	0.085	0.085	0.151	0.152	0.144	0.147

t-statistics in parentheses; * p<0.1 is significance at 10%; , ** p<0.05 is significance at 5%; and *** p<0.01 is significance at 1%

Appendix A5.5: OLS Impact of improved and certified cassava seed adoption on household welfare

VARIABLES	*Effect of adoption* Log of per capita HH consumption expenditure (UGX'000)		Log of per capita HH cassava cash income (UGX'000)		*Effect of adoption intensity* Log of per capita HH consumption expenditure (UGX'000)		Log of per capita HH cassava cash income (UGX'000)	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1 if used improved seed	0.00357		0.724***					
	(0.0913)		(3.942)					
1 if used improved uncertified		-0.0187		0.537***				
		(-0.446)		(2.730)				
1 if used improved certified seed		0.0631		1.222***				
		(1.109)		(4.580)				
Area improved seed					0.0123		0.354***	
					(1.064)		(6.669)	
Area improved certified seed						0.0233*		0.322***
						(1.783)		(5.271)
1 if AIP Member	0.0550	0.0479	-0.204	-0.263	0.0460	0.0424	-0.360	-0.265
	(1.030)	(0.894)	(-0.814)	(-1.049)	(0.856)	(0.794)	(-1.455)	(-1.064)
HH Education years	0.0529***	0.0529***	0.0913**	0.0907**	0.0523***	0.0521***	0.0843**	0.0909**
	(6.346)	(6.342)	(2.328)	(2.322)	(6.281)	(6.267)	(2.195)	(2.341)
1 if received extension	0.0573	0.0501	0.609**	0.549**	0.0528	0.0507	0.524**	0.566**
	(1.119)	(0.975)	(2.529)	(2.277)	(1.030)	(0.991)	(2.218)	(2.370)
TLU 2015	0.0238***	0.0235***	0.0345	0.0317	0.0230***	0.0228***	0.0198	0.0292
	(4.207)	(4.148)	(1.295)	(1.195)	(4.052)	(4.036)	(0.757)	(1.104)
1 if own TV	0.239***	0.230***	0.438	0.358	0.231***	0.228***	0.234	0.322
	(3.772)	(3.604)	(1.470)	(1.199)	(3.620)	(3.592)	(0.797)	(1.085)
1 if HHH is female	-0.0149	-0.0153	-0.221	-0.224	-0.0129	-0.0106	-0.186	-0.186
	(-0.296)	(-0.304)	(-0.935)	(-0.951)	(-0.257)	(-0.210)	(-0.802)	(-0.790)
Age of HH head	0.000268	0.000200	-0.000809	-0.00138	0.000244	0.000311	-0.00128	2.76e-05
	(0.187)	(0.140)	(-0.120)	(-0.206)	(0.170)	(0.218)	(-0.195)	(0.00413)
Family size	-0.0830***	-0.0822***	-0.156***	-0.150***	-0.0826***	-0.0815***	-0.140***	-0.131***
	(-12.69)	(-12.54)	(-5.081)	(-4.868)	(-12.62)	(-12.41)	(-4.632)	(-4.274)
Kms to parcel	0.0457***	0.0450***	0.128*	0.122*	0.0427***	0.0401**	0.0444	0.0531
	(2.995)	(2.949)	(1.787)	(1.709)	(2.755)	(2.576)	(0.622)	(0.731)
Total land operated (Acres)	-0.00161***	-0.00155***	0.000866	0.00135	-0.00160***	-0.00158***	0.00126	0.00121

	(-2.829)	(-2.723)	(0.323)	(0.504)	(-2.801)	(-2.778)	(0.479)	(0.455)
1 if titled land	0.0248	0.0180	0.216	0.159	0.0195	0.0149	0.0599	0.0772
	(0.447)	(0.322)	(0.828)	(0.608)	(0.349)	(0.267)	(0.233)	(0.297)
1 if rented in land	0.0909	0.0858	0.472	0.429	0.0857	0.0793	0.370	0.364
	(1.339)	(1.263)	(1.477)	(1.348)	(1.260)	(1.165)	(1.181)	(1.147)
1 if customary land	-0.0494	-0.0496	0.490**	0.489**	-0.0524	-0.0536	0.397**	0.424**
	(-1.221)	(-1.226)	(2.576)	(2.579)	(-1.292)	(-1.326)	(2.126)	(2.242)
Total people reliable upon	0.000175	0.000199	0.00231	0.00250	0.000165	0.000221	0.00234	0.00332*
	(0.406)	(0.461)	(1.137)	(1.239)	(0.382)	(0.514)	(1.181)	(1.649)
Log of asset value (UGX'000)	0.0727***	0.0725***	0.314***	0.312***	0.0717***	0.0716***	0.301***	0.315***
	(4.058)	(4.048)	(3.725)	(3.718)	(4.007)	(4.010)	(3.645)	(3.776)
1 if accessed credit	0.0789**	0.0806**	0.0994	0.114	0.0806**	0.0793**	0.158	0.114
	(2.119)	(2.166)	(0.568)	(0.654)	(2.165)	(2.134)	(0.919)	(0.658)
1 if suffered drought shock	0.00424	0.00209	-0.156	-0.174	0.00306	0.00146	-0.161	-0.163
	(0.109)	(0.0540)	(-0.858)	(-0.959)	(0.0790)	(0.0378)	(-0.904)	(-0.903)
1 if suffered flood shock	0.0213	0.0225	-0.0874	-0.0772	0.0210	0.0203	-0.0497	-0.0507
	(0.402)	(0.425)	(-0.351)	(-0.311)	(0.397)	(0.385)	(-0.204)	(-0.206)
1 if suffered crop Pest D'se Shock	0.0339	0.0346	-0.347*	-0.342*	0.0328	0.0326	-0.331*	-0.314
	(0.785)	(0.801)	(-1.710)	(-1.690)	(0.763)	(0.758)	(-1.665)	(-1.562)
1 if Mid-Western region	0.0623	0.0569	0.416*	0.371	0.0584	0.0536	0.291	0.284
	(1.236)	(1.128)	(1.757)	(1.570)	(1.156)	(1.062)	(1.252)	(1.202)
1 if Northern region	0.0941*	0.0811	0.509**	0.400*	0.0942*	0.0919*	0.484**	0.450**
	(1.938)	(1.644)	(2.228)	(1.731)	(1.942)	(1.898)	(2.166)	(1.987)
Constant	6.173***	6.183***	0.599	0.686	6.187***	6.188***	1.000	0.789
	(35.24)	(35.29)	(0.728)	(0.835)	(35.24)	(35.36)	(1.236)	(0.966)
Observations	700	700	700	700	700	700	700	700
R-squared	0.397	0.399	0.205	0.213	0.398	0.400	0.237	0.219

t-statistics in parentheses; * p<0.1 is significance at 10%; , ** p<0.05 is significance at 5%; and *** p<0.01 is significance at 1%

Appendix A5.6: Household survey questionnaire

NATIONAL AGRICULTURAL RESEARCH ORGANISATION (NARO)
NATIONAL CROPS RESOURCES RESEARCH INSTITUTE (NaCRRI)
NATURAL RESOURCES INSTITUTE (NRI)
UNIVERSITY OF GREENWICH
CASSAVA SEED SYSTEM PROJECT

Corresponding address:
NATIONAL CROPS REOSOURCES RESEARCH INSTITUTE (NaCRRI),
P.O.BOX 7084, KAMPALA
TEL:
Email:

INTRODUCTION

I am here on behalf of MAAIF-NARO-NaCRRI-NRI-UoG to carry out student research on issues relating to cassava innovation systems, cassava seed access and use, cassava production and welfare changes resulting from use of improved certified seed and use of improved cassava varieties. The ultimate aim of this study is to understand the (a) performance and impact of cassava Agricultural Innovation System (AIS) initiatives, (b) determinants of cassava seed access source choice, (c) determinants of cassava technology adoption, (d) production and welfare of cassava technology adoption. Your honest responses will only be used to inform NaCRRI's CSS project of the research objectives listed above and will therefore be treated with utmost confidentiality. The research is being conducted through a PhD programme registered at the Natural Resources Institute of the University of Greenwich, UK. Your participation is highly valued. *You are free to ask me anything about this survey*. *Consent given 1= Yes, 2= No; If yes, thank and proceed*!
Thank you for accepting to take part in this study.

NOTE: DATA REFERENCE PERIOD IS LAST SEASON (S); CASSAVA SEASON IS 12 MONTHS WHILE OTHER CROPS IT IS 3-6 MONTHS. THEREFORE, WE CONSIDER TWO (1ST & 2ND) SEASONS FOR THE 3 OTHER MAJOR CROPS. REFERENCE YEAR IS 2015.

Section 1: Identifying information:

Enumerator's: Name……………………………………………… Phone #……………………………Date………………………………..	**Team-leader Name………..………………Phone #……………………………Check Sign…………….**

Classifying information			
Region		Parish	
District		Village	
Sub-county		Household ID & Phone number of HH Head	

Section 2: House description

Main house description (*The enumerator to observe/establish the following*), If not at home, ask) [Circle the correct answer]

#	Main House description	Codes		Answer
1	Roofing material of the main house	1 = Grass; 2 = Iron sheet; 3 = Tiles; 4 = Banana fibres; 5 = Others (Specify) __________		
2	Wall materials of the main house	1= Mud burnt bricks; 2= Mud un-burnt bricks; 3= Cement Bricks/stone; 4 = Iron sheets; 5 = Wood;		
3	Floor material of the main house	1 = Earth/ cow dung; 2 = Cement; 3 = Wood; 4 = Tiles, 5=Others (Specify) ___________________		
4	Type of toilet use	1=Flash toilet; 2= Pit latrine; 3= Bucket latrine; 4= No latrine /open air		
5	Number of rooms in main house?	…………………………………………………………………		
6	How many other houses do you own?	…………………………………………………………………		

Section 3: Respondent and general household information

Type of household: 1= Male headed; 2= Female headed; 3=Child headed; 4= Other (specify)………………….

PERSON ID	List family members who lived in this household for at least 6 months in the last 12 months	SEX: 1=M; 2=F	What is the relationship of [NAME] to the head of the household? 1= Head 2= Spouse 3= Son/daughter 4= Grand child 5= Parent of head or spouse 6= In-laws 7= Nephew/Niece 8= Other relatives 9= Servant 10= Non-relative 11= Other (specify)	AGE [NAME] Full Years	Education level completed (with certificate) 1=None; 2=Primary , 3=Secondary (ordinary level), 4=Secondary(advanced level) 5=Tertiary	Complete years of schooling	**Marital Status** 1=Married living with spouse, 2=Married but spouse away, 3=Divorced/separated, 4=Widow/ widower, 5=Not married,	**<u>Main</u> Occupation** 1=None 2=Farming, 3=Salaried employment off-farm 4= Salaried employment on-farm 5= Casual labor on farm 6=Casual labor off-farm 7=Self-employed off-farm 8=Housekeeping, 9=Student 10=Other (Specify)_______	Was [NAME] chronically ill for 3 months in the past year (2015)? 1=Yes; 0=No
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
01									
02									
03									
04									
05									
0									

6									
07									
08									
09									
10									
11									
12									
13									
14									
15									
16									
17									
18									
19									
20									

Section 4: Land ownership and tenure

In the last 12 months, how many parcels of land did you have access to in total? ____ How many were under improved variety cassava_______? Local variety_____?

Note: Parcel is one continuous piece of land. In one parcel, there may be different gardens planted with different crops. Begin with cassava gardens

Parcel #	Parcel Name	Size of the parcel (acres)	Distance from Home in KMs	**Main land use** 1 = Crop production 2 = Livestock keeping 3= Fish farming 4 = Homestead 5 = Woodlot/forestry 6 = Others (Specify)…………	1= Mono-cropping/pure stand 2=Mixed -cropping 3=Under Fallow 4=Partially cultivated with parts under fallow	If parcel is cropped, name the **most important** crop planted on the parcel- *begin with cassava Parcels*)-see crop codes	Proportion of the parcel under **cassava (**in acres) (Fraction)	**Land ownership/ access** 1 =Owned with title 2 =Owned without title 3 = Rented from other individual; 4=Borrowed for free 5 = Communal	**Tenure System** 1= Freehold 2= Leasehold 3= Mailo 4= Customary 6= Other (specify)	**Mode of acquisition** 1 = Purchased 2 = Inherited; 3= Government allocation 5 = Lease 4 = Rented 6=Sharecropped; 7 = Borrowed free 8=Communal land	Who manages & makes decisions Decisions concerning the timing of cropping activities, crop choice and input use? 1=Husband; 2=Wife; 3=Both; 4=Children; 5=All 6=Others (specify Person ID……………………
1	2	3	4	5	6	7	8	9	10	11	12

1											
2											
3											
4											
5											
6											
7											

Crop Codes (Note: Code is in front of crop NOT behind it)

Roots and Tubers	**Code**	**Cereals**	**Code**	**Legumes**	**Code**	**Perennial cash crops**	**Code**	**Fruits**	**Code**	**Vegetables**	**Code**	**Oil seed crops**	**Code**
Cassava	**1**	Maize	**6**	Beans	**12**	Coffee	**19**	Oranges	**26**	Cabbages	**31**	Simsim	38
Sweet Potatoes	**2**	Finger millet	**7**	Ground nuts	**13**	Cotton	**20**	Mango	**27**	Tomatoes	**32**	Sunflower	39
Irish Potato	**3**	Sorghum	**8**	Cow pea (imare, ngor, enkuku)	**14**	Cocoa	**21**	Passion Fruit	**28**	Onions	**33**	**Others (specify)**	
Bananas	**4**	Rice	**9**	Pigeon peas (shrub) (lapena)	**15**	Tea	**22**	Pineapple	**29**	Carrots	**34**	Forest	40
Yam	**5**	Barley	**1**	Field peas (kawo)	**16**	Vanilla	**23**	Paw Paw	**30**	Egg plants	**35**		41
		Wheat	**11**	Soya beans	**17**	Tobacco	**24**			Ginger	**36**		42
				Green gram (choroko)	**18**	Sugar cane	**25**			Curry	**37**		43

13. How much did you pay on <u>average</u> for each acre you rented per season in 2015? ______________________________ b) per year? ___________________________

14. Did u you rent out land last year? 1=Yes; 2=No (Circle that apply). If yes, how many acres did you rent out? ________acres

15. If you rented out part of your land last year, how much did you charge per acre? ______________ UgX

Section 5: Crop production, seed use and sales in the last cropping season [Cassava is for last 12 months WHILE OTHER 3 MAJOR CROPS, it's for <u>both</u> seasons of 2015. *Begin with cassava Parcels*

Parcel # (copy parcel # from **section 4**)	Parcel Name (copy name from **section 4**)	Crops grown (Begin with cassava and 3 other major crops (**see crop codes on page**	Area planted (Acres)	Major Type of seed/ seedling planted 1=Improved; 2= Traditional 3=Don't know	Improved or local DORMINANT variety Name (See *cassava variety codes below*) Note: Write ONE MAJOR variety name of other crops	Number of Years growing variety	**Main source of seed** 1= Own saved/ fellow farmer 2=Government sources (NARO & NAADS 3=N GO (Name…………………) 4= Cassava Seed Entrepreneurs (CSEs) 5=Agro-dealers/ seed company for beans, vegetable seed & grains etc.)	Seed quality 1= Certified/ Quality declared 2= Uncertified ; 3=Don't know	Seed quantity planted (Bags for cassava); Kgs for other	Cost of seed per unit (UGX) [even if seed was received for free]	Products harvested/ processed **Codes** 1-8 =list provided below 9= Grains 10=Others **(Circle all that apply)**	Total Quantity ***<u>harvested/ processed</u>*** Kgs	Quantity Lost (Kgs)	**Main Cause of loss** 1=Insects 2=Rodents 3= Flood 4= Stolen 5. Fire 6. Pests/ disease 6=Other (specify)	Quantity utilized at home (Kgs)	Quantity given away for free (Kgs)	Quantity sold (Kgs)	Price per Unit (UGX)	Major buyer 1= Fellow farmer 2=Gov't (NAADS) 3=NGO 4=CSE 5=Seed trader 6=Foreigner	Major Decision maker on product & income utilization 1= Husband 2= Wife 3= Children 4=All
1											1=Stems/se									
											2=Fresh									
											3=Dry chips									
											4=Flour									
											5=Boiled/ro									
											6=Mandazi/									
											7= Bread									
											8=Waragi									
2											1=Stems/se									
											2=Fresh									
											3=Dry chips									
											4=Flour									
											5=Boiled/ro									

											6=Mandazi/									
											7= Bread									
											8=Waragi									
3											1=Stems/se									
											2=Fresh									
											3=Dry chips									
											4=Flour									
											5=Boiled/ro									
											6=Mandazi/									
											7= Bread									
											8=Waragi									
#	**3 Other Major**																			

Crop Codes (*Note: Code is in front of crop NOT behind it***)**

Roots and Tubers	**Code**	**Cereals**	**Code**	**Legumes**	**Code**	**Perennial cash crops**	**Code**	**Fruits**	**Code**	**Vegetables**	**Code**	**Oil seed crops**	**Code**
Cassava	**1**	Maize	**6**	Beans	**12**	Coffee	**19**	Oranges	**26**	Cabbages	**31**	Simsim	38
Sweet Potatoes	**2**	Finger millet	**7**	Ground nuts	**13**	Cotton	**20**	Mango	**27**	Tomatoes	**32**	Sunflower	39
Irish Potato	**3**	Sorghum	**8**	Cow pea (imare, ngor, enkuku)	**14**	Cocoa	**21**	Passion Fruit	**28**	Onions	**33**	**Others (specify)**	
Bananas	**4**	Rice	**9**	Pigeon peas (shrub) (lapena)	**15**	Tea	**22**	Pineapple	**29**	Carrots	**34**	Forest	40
Yam	**5**	Barley	**1**	Field peas (kawo)	**16**	Vanilla	**23**	Paw Paw	**30**	Egg plants	**35**		41
		Wheat	**11**	Soya beans	**17**	Tobacco	**24**			Ginger	**36**		42
				Green gram (choroko)	**18**	Sugar cane	**25**			Curry	**37**		43

Cassava variety codes

Improved variety codes: 1= NASE Series including 4271, 2961, Nigeria/Migera/La Soroti; 2=NAROCAS 1 or NAM 130; 3=Don't Know

Local variety Codes: 4= Nyaraboke; 5=Alado Alado; 6=Tim Tim; 7=Bwana Tereka; 8=Bukalasa series including Njule; 9=Others (specify) ______________________

Section 6: Agrochemical input use at parcel level (in the year 2015)

Did you use any Agrochemical (organic fertilizer, inorganic fertilizer, herbicides, and pesticides)? 1= If you used any; 2= If you used non; [**SKIP TO NEXT SECTION**]

Parcel #	Parcel Name	**ORGANIC FERTILISER**				**INORGANIC FERTILIZER**				**HERBICIDES**				**PESTCIDES**			
		Quantity used (Kgs)	Was any of this purchased? 1= Yes, 2= No	Quantity purchased (Kgs)	Unit cost per Kg (even if it Is free)	Quantity used (Kgs)	Was this purchased? 1= Yes, 2= No	Quantity purchased (Kgs)	Unit cost per Kg (Note: Fertilizers are sold in 50 kg bag)	Quantity used (Kgs/Ltrs)	Was this purchased ? 1= Yes, 2= No	Quantity purchased (Kgs/Ltrs)	Unit cost UGX	Quantity used (Kgs/Ltrs)	Was this purchased? 1= Yes, 2= No	Quantity purchased (Kgs/Ltrs)	Unit cost UGX
Cassava																	
3 MAJOR CROPS				**Sum up all per other major crop**													

Section 7: Labour and machinery use in the last 12 months (2015) [Note: cassava season is full year while others have two seasons in one year]

Labour is for all tasks in the last cropping season: land preparation, planting, input application, weeding, harvesting transportation, post-harvest work, etc as broken down below

Parc	Parc el	FAMILY LABOUR				HIRED LABOUR				NON-HIRED LABOUR (Work free of charge) capture costs			MACHINE USE				
		Labor activities	How many family members worked on this [parcel]	How many days did each work on average?	Age of laborer (see codes below) list all that apply	How many laborers worked on this [parcel]	Age of laborer (see codes below) list all that apply	How many days did each work?	Amount (UGX) paid per laborer per day	How many laborers worked on this [parcel]	Age of laborer (see codes below) list all that apply	How many days did each work?	Did you use any machines last season on this [Parcel] 1=Yes, 2=No	Was the machine hired or owned? 1= Owned, 2= Hired	Cost of hire (Put 0 if borrowed for free)	If owned, purchase price	Year of purchase
1		Clearing															
		Ploughing															
		Planting															
		Weeding															
		Input application															
		Harvesting stems															
		Harvesting roots															
		Processing															
2		Clearing															
		Ploughing															
		Planting															
		Weeding															
		Input application															
		Harvesting stems															
		Harvesting roots															
		Processing															
3		Clearing															
		Ploughing															
		Planting															
		Weeding															
		Input application															
		Harvesting stems															
		Harvesting roots															
		Processing															
3 OTHER MAJOR CROPS			**Sum up all costs per other major crop**														

<u>Laborer Age codes</u>: 1=<9 years; 2=9-15 &>49 years; 3=16-49 years

Section 8: SOCIAL CAPITAL AND NETWORKING (FARMER GROUP MEMEBERSHIPS)
Membership in formal and informal organizations and institutions <u>in the last 5 years</u> (household head & spouse(s). One group membership per row)

Family Member ID (Ref. Sec. 3)	Type of group HH head/ spouse is/was a member of (Codes A)	Most important group function (Codes B)	Period of membership in months	Role in group (Codes C)	Still a member now 1=Yes, 2=No	If No, reason for leaving? (Codes D)
1	**2**	**3**	**4**	**5**	**6**	**7**
<u>Codes A</u> 1. Farmer group/union/input supply 2. Crop/seed producer and marketing group 3. Women's association 4. Men's' association 5. Youth Association		6. Church association/ congregation 7. SACCO 8. Funeral association 9. Local council 10. Water users association 11. Others (specify)……..	**<u>Codes B.</u>** 1.Input access/marketing 2. Produce marketing 3. Seed production 4.Farmer research group 5.Savings & credit	6. Funeral group 7. Tree planting 8. Soil & water conservation 9. Church group 10. Input credit 11. Others (specify)	**<u>Codes C</u>** 1.Official 2. Ex-official 3. Ordinary member	**<u>Codes D</u>** 1.Organisation wasn't useful 2. Poor management 3.Unable to pay subscription fee 4. Group closed

SOCIAL NETWORKS	**In this village**		**In other villages**		**Quantity in bags**		**Cost per bag in UGX**	
	Relatives	**Non relatives**	**Relatives**	**Non relatives**	**Relatives**	**Non relatives**	**Relatives**	**Non relatives**
Number of people you can rely on for support in times of need (all problems)								
Number of people from whom you can access cassava seed								
Number of people who can buy your cassava seed								

Section 9: LIVESTOCK OWNERSHIP AND SALES

Livestock type	Number of livestock at the end of 2015 cropping season (including bought ones)	Number of livestock owned at the end of 2010 cropping season	For 2015, if you would sell one of the [….} how much would you receive from the sale? (UGX)	How many of the livestock did u sell in the last 12 months	Cost per unit (UGX)
Cows					
Bulls					
Trained oxen for					
Goats					
Sheep					
Donkeys & mules					
Horses					
Chicken					
Occupied Bee-hives					
Pigs					

Turkeys					
Guinea fowls					
Rabbits					
Ducks					
Dogs					
Cats					
Fish					

Section 10: NON CROP INCOME IN THE LAST ONE YEAR (2015)

Was any non-crop income earned in the last year of 2015? 1=Yes, 2=No (If no, skip to next section) [If many HH members earn from same income source, fill according to the earning family member in separate rows]

Family member (code) [Copy family member code from section 1]	Non-crop Income source (copy codes from below)	Unit of earning (E.g. month, weekly or daily or hourly) –Use this to compute for the whole yr	No. of units worked/received	Amount per unit (Cash and in kind)	
				Cash (UGX)	Payment in kind (Cash equivalent)
1	**2**	**3**	**4**	**5**	**6**

INCOME CODES

1=Rented/Sharecropped out land	6=Rental property (other than land	11=Remittances sent from non-residential family and relatives living elsewhere
2=Rented out oxen for ploughing	7=Pension Income	12=Other business NET income (shops, trade, tailor, sales of beverages etc. **NB**: ***Cassava bi-product beverages were captured under Section 5)***
3=Salaried employment	8=Drought/food relief	13.=Sales of firewood, brick making charcoal making, poles etc.
4=Farm labor wages	9=Safety net or food for work	14=Quarrying stones, Sand and marrum
5=Non-farm labor wages	10=Marriage gifts	15=Non-farm agribusiness NET income (e.g. grain milling and trading);

Section 11: WELFARE AND FOOD SECURITY

Is cassava an important Food Security crop in this household? (Circle that applies) 1= Yes 2= No. If yes, how many parts out of 10, does cassava contribute to this household Food Security? __________

#	Description of welfare and food security aspect	Answer
1	State the ID Code of the respondent to this section	
2	Does every member of the household have at least two sets of clothes? 1= Yes 2= No	
3	Does every child in this household (all those under 18 years old) have a blanket? 1= Yes; 2= No; 3=Not Applicable	
4	Does every member of the household have at least one pair of shoes? 1= Yes; 2= No	
5	How many meals, including breakfast are taken per day in your household?	
6	Did u ever run out of salt in 2015 and you were unable to buy? 1=Yes; 2=No (circle that applies) If yes, what did you do when you last ran out of salt?	
	1= Borrowed from neighbors; 2= Bought on credit; 3= Did without; 4= Did not cook at all; 5=Not applicable	
7	*FOR HOUSEHOLD WITH CHILDREN UNDER AGE 5 (IF NONE, WRITE 12)*	
	What did your children below 5 years old (0-4 years) have for breakfast yesterday?	
	1=Tea/drink with sugar 2=Milk/milk tea with sugar 3=Solid food only 4=Tea/drink with solid food 5=Tea/drink without sugar with solid food 6=Porridge with solid food 7=Porridge with sugar 8=Porridge with milk 9=Porridge without sugar 10= Solid food with water 11=Nothing 12=No under 5s in the HH 13= Milk/milk tea without sugar 14=Other (Specify	
8	*HOUSEHOLD WITH CHILDREN 5-13 (IF NONE, WRITE 12)*	
	What did your children between 5 to 13 years old have for breakfast yesterday? (***see codes below)***	
	01=Tea/drink with sugar 02=Milk/milk tea with sugar 03=Solid food only 04=Tea/drink with solid food 05=Tea/drink without sugar with solid food 06=Porridge with solid food 07=Porridge with sugar 08=Porridge with milk 09=Porridge without sugar 10=Solid food with water 11=Nothing 13=Other (Specify) 12=No 5-13 in the HH	
9	Have you been faced with a situation when you did not have enough food to feed the household in the last 12 months? 1=Yes [>>go to 10] 2=No **[>>go to Section 12]**	

10	11	12
When did you experience this situation? *INTERVIEWER: CIRCLE ALL THAT APPLY.* **1. January** **2. February** **3. March** **4. April** **5. May** **6. June** **7. July** **8. August** **9. September** **10. October** **11. November** 12. **December**	Food Coping strategies. **Circle all that apply** 1 Received relief food 1=Yes; 2=No 2 If received relief food, please indicate the sources 1 = Government, 2 = NGOs, 3 = Other sources (Specify) __________________ 3 Borrowed money to buy food 4 Got food on credit 5 Reduced the number of meals 6 Substituted commonly bought foods with cheaper kind 7 Mortgaged/sold assets 8 Borrowed from neighbours 9 Went for food for work programmes 10 Others (specify)	**Why did u not have enough food in reference to 9 above?** *DON'T READ OUT THE ANSWERS, CIRCLE ALL THAT APPLY.* 1. Because of inadequate household stocks due to drought/poor rains 2. Inadequate food stocks from previous season because insecurity prevented us from harvesting the crop 3. Inadequate household food stocks because of pest damage to crop 4. Inadequate household food stocks because we did not plant enough 5. We did not have enough money to buy food from the market 6. Food in the market was very expensive 7. No one was willing to offer us some food 8. We could not cook because we had no fuel wood 9. There was no food distribution 10. Bread winner/head of household died or moved away 11. We were not able to reach the market because of distance or insecurity or lack of transport 12. There was no food in the market 13. Floods / water logging 14. Other (Specify)

Section 12: SHOCKS & COPING STRATEGIES (Testing if households producing cassava are more resilient against different form of covariate and idiosyncratic shocks)

Code	Description of distress events	Did you experience [SHOCK] during the past 12 months? **1 = Yes** 2 = No **(>> NEXT SHOCK)**	When did the [SHOCK] first occur? 1=Jan 7=July 2=Feb 8=Aug 3=Mar 9=Sept 4=Apr 10=Oct 5=May 11=Nov 6=Jun 12=Dec	How long did the shock last? *(RECORD NUMBER OF MONTHS) IF LESS THAN 1 MONTH RECORD '00'*	As a result of the [SHOCK], was there a decline in your household's? **1 = Yes 2 = No**				How did your household cope with this [SHOCK]? *UP TO 3 ANSWERS WITH RANK FOR EACH SHOCK EXPERIENCED. USE CODES BELOW.*		
					Income	Assets	Food Production	Food Purchases	**1st**	**2nd**	**3rd**
		1	**2A**	**2B**	**3A**	**3B**	**3C**	**3D**	**4A**	**4B**	**4C**
101	Drought/Irregular Rains										
102	Floods										
103	Landslides/Erosion										
104	Unusually High Level of Crop Pests & Disease										
105	Unusually High Level of Livestock Disease										
106	Unusually High Costs of Agricultural Inputs										
107	Unusually Low Prices for Agricultural Output										
108	Reduction in the Earnings of Currently (Off-Farm) Employed Household Member(s)										
109	Loss of income sources (s) (Not Due to Illness or Accident)										
110	Serious Illness or Accident of Income										

Code	Description of distress events	Did you experience [SHOCK] during the past 12 months? **1 = Yes** 2 = No **(>> NEXT SHOCK)**	When did the [SHOCK] first occur? 1=Jan 7=July 2=Feb 8=Aug 3=Mar 9=Sept 4=Apr 10=Oct 5=May 11=Nov 6=Jun 12=Dec	How long did the shock last? *(RECORD NUMBER OF MONTHS) IF LESS THAN 1 MONTH RECORD '00'*	As a result of the [SHOCK], was there a decline in your household's? **1 = Yes 2 = No**				How did your household cope with this [SHOCK]? *UP TO 3 ANSWERS WITH RANK FOR EACH SHOCK EXPERIENCED. USE CODES BELOW.*		
	Earner(s)										
					Income	Assets	Food Production	Food Purchases	**1st**	**2nd**	**3rd**
		1	**2A**	**2B**	**3A**	**3B**	**3C**	**3D**	**4A**	**4B**	**4C**
111	Serious Illness or Accident of Other Household Member(s)										
112	Death of Income Earner(s)										
113	Death of Other Household Member(s)										
114	Theft of Money/Valuables/Non-Agricultural Assets										
115	Theft of Agricultural Assets/Output (Crop or Livestock)										
116	Conflict/Violence										
117	Fire										
118	Animals invading										
119	Other (Specify)										

CODES FOR COLUMN 4A, 4B, 4C

1 = Unconditional help provided by relatives/friends 2 = Unconditional help provided by local government 3 = Changed dietary patterns involuntarily (Relied on less preferred food options, reduced the proportion or number of meals per day, skipped days without eating, etc…) 4 = Changed cropping practices (crop choices or technology)	5 = Household member(s) took on more non-farm (wage- or self-) employment 6 = Household member(s) took on more farm wage employment 7 = Household member(s) migrated 8 = Relied on savings	9 = Obtained credit 10 = Sold durable household assets (agricultural or non-agricultural) 11 = Sold land/building 12 = Rented out land/building	13 = Distress sales of animal stock 14 = Sent children to live elsewhere 15 = Reduced expenditures on health and education 96=Other (specify

Section 13: TRANSPORT SERVICES AND ROAD INFRUSTRUCTURE

Service #	Road Type	Do you have a […….] in your community (sub-county)? 1=Yes 2=No **(>>NEXT ROAD)**	What is the commonest mode of transport used to reach the nearest [ROAD]? 1= Walking 2= Taxi (car) /minibus 3= Boda-boda 4= Bus 5= Owned Motorcycle 6= Owned Bicycle 7= Boat 8=Owned vehicle 9= Other (Specify)	How long does it take you to travel to the nearest [ROAD] using the commonest means? **TIME IN MINUTES**	Is the road usable all the year round? 1=Yes (>>6A) 2=No (>>6B)	What is the distance from your household to an all year usable road KILOMETERS	Why was the road unusable? 1=Bad weather 2=Bad terrain 3=Potholes 4=Poor drainag 5=Bushy roads 6=Insecurity 8=Other (specify)
	1	**2**	**3**	**4**	**5**	**6A**	**6B**
A	Main road (Tarmac)						
B	Main road (Murram)						

C	District/feeder road						
D	Community (sub-county) Access Road						

What is the distance from your household to the nearest public transport point/stage? (Km)…………………	What type of road is this public transportation point/stage?		What is the distance from your household to the nearest all weather road? (Km)……………………….
	1= Main road (Tarmac)	2= Main road (Murram)	
	3= District/feeder road	4= Community (sub-county) Access Road	
	8=Other (specify)		

Section 14: HOUSEHOLD ASSETS

Now I would like to ask you about assets owned by your household (2010 & CURRENT TIME).

Type of assets	Asset code	Number owned 2010/11	Number Currently owned	Total current estimated value (in UGX)	What is the reason for the change in number of asset ownership between 5 years ago and now? (See codes)	**CODES**
1 (Household Assets)	**2**	**2A**	**2B**	**3**	**4**	1= Sold Asset 2= Asset Destroyed 3= Asset Given Away 4= Asset Stolen 5= An old member of the HH took them with him/her 6 = Purchased additional asset 7= Received Gift/inheritance of additional asset 8= A new member to the HH brought them with him/her 9=N/A 99=Others (specify)…………………
House	**01**					
Other Buildings	**02**					
Land (acres)	**03**					
Furniture/Furnishings	**04**					
Household Appliances e.g. Kettle, Flat iron, etc.	**05**					
Television	**06**					
Radio/Cassette	**07**					
Generators	**08**					
Solar panel/electric inverters	**09**					
Bicycle	**10**					
Motor cycle	**11**					
Motor vehicle	**12**					
Boat	**13**					
Jewelry and Watches	**15**					
Mobile phone	**16**					
Computer & accessories	**17**					
Other household assets e.g. lawn mowers, etc.	**20**					
Other 1 (specify)	**21**					

Section 15: ACCESS TO CREDIT SERVICES BEFORE AND AFTER ADOPTION

Did you have access to credit in 2010 for? 1=Yes; 2=No	Did you borrow money for any reason in 2010/11? 1=Yes, 2=No
How much did you borrow in total in 2010 (UGX)?	Did you have access to credit in the last year 2015? 1 = Yes [ ], 2 = No [ ], **If No, skip to section 16.**

If yes, please provide the following details

SOURCE of Credit	Have you ever borrowed from [SOURCE] (1=Yes, 2=No)	Amount borrowed (UGX)	Major Purpose (see codes)	SOURCE of Credit	Have you ever borrowed from [SOURCE] (1=Yes, 2=No)	Amount borrowed (UGX)	Major Purpose (see codes)
1=Employer				6=SACCOs			
2=Relative and friends				7=NGO			
3=Informal savings and credit group				8= Faith based organizations			
4=Money lender				9=Bank or micro-finance institution			
5=Government credit schemes				10=Others (specify)………………			

Purpose for borrowing: 1= Purchase of food, 2 = Purchase of household assets, 3 = Payment of fees, 4= Cover medical costs, 5 = Crop production, 6 = Livestock production, 7 = Buying land, 8 = Buying construction material, 9 = Marriage costs, 10 = Buying transport means, 11= Buy oxen, 12 = Non-farm business, 13 = For trade 14 = Others (specify)……………………………..

Section 16A: AGRICULTURAL INNOVATION SYSTEMS (AIS/AIP) AND ACCESS TO EXTENSION SERVICES
NOTE: AIS/AIP= Farmers coming together to solve their common challenges with the involvement of other actors e.g. NGOs, Gov't, NAADS, NARO, Traders, Private sector). AIS/AIP is different from a mere farmer organization/group which may not involve other actors as listed above. *PROBE for Cassava Seed System/CSE & EAAPP-CRCoE AIP/AIS PROJECT Initiatives.* **Following my explanation, were you a member of any cassava AIP or did you participate in any AIP? 1 = Yes; 2= No**

Question	**2010**	**2015**
Did this HHD receive any extension services in 2010; 2015? 1= Yes, 2= No (Put answer in next two columns)		
Who provided the extension service? **CODES** 1=Own information search (specify source of information & knowledge-pathways), 2= Fellow farmer, 3= CSE, 4= NGO, 5= NARO (Research), 6= NAADS (Gov't extension), 7=Others (Specify)……………………………..		
How many times did you receive the extension service in a year? __________		
Has any member of your household participated in prioritizing enterprises to demand for advisory services under NAADS programs, Agricultural Innovation Platforms? 1= Yes, 2= No		
Has any member of your household participated in a training program organized by NAADS/NGOs and government institutions? 1= Yes, 2= No If yes, specify agency		
Who provided the training? 1= Fellow farmer, 2= NGO, 3= NARO (Research), 4= NAADS (Gov't extension), 5=CBOs; 6=Others (Specify)……………………………..		
What were you trained on? (circle all that apply) 1= Improved varieties, 2= Pest and Disease control, 3= Agronomic practices, 4= Value addition and processing, 5= Mechanization, 6= Group formations, 7= Marketing and agribusiness management		
Are you using the knowledge gained from training? 1. Yes 2. No		
Which knowledge are you applying? (circle all that apply) 1= Improved varieties, 2= Pest and Disease control, 3= Agronomic practices, 4= Value addition and processing, 5= Mechanization, 6= Group dynamics, 7= Marketing and agribusiness management		

If not applying now, what are the reasons? (Circle all that apply) 1=High costs, 2= It didn't work; 3= Lack of interest; 4=Inaccessibility; 5= Other (specify)……………………….		

Section 16B: KAPS ASSESSMENT

NOTE: AIS/AIP= Farmers coming together to solve their common challenges with the involvement of other actors e.g. NGOs, Gov't, NAADS, NARO, church, Private sector). AIS/AIP is different from a mere farmer organization/group which may not involve other actors as listed above. *PROBE FOR Cassava Seed System/CSE & EAAPP-CRCoE AIP/AIS Project Initiatives.* **With respect to your AIP, State whether you strongly Disagree (SDA), Disagree (DA), are undecided (UD), agree (A), strongly agree (SA) with the following statements: Tick the respondent's choice**

KNOWLEDGE, ATTITUDES, PRACTICES (KAPS) [Specify Respondent Code……………………..Section 2)		**SDA**	**DA**	**UD**	**A**	**SA**
Knowledge						
1	I get knowledge and skills from fellow farmers in the cassava IP and from government and NGO agents					
2	My knowledge, skills on timing of planting season, seed sourcing, planting, spacing, soil management, weeding, harvesting has improved					
3	I am well informed of where to get quality seed, farm implements and market prices beforehand					
4	I have received training on several aspects of cassava production, value addition and marketing					
5	I know the importance of providing feed-back to other actors in my cassava IP					
Attitudes						
1	My level of interest in using certified seed of improved varieties for cassava and other crops has improved					
2	Growing certified seed of improved cassava varieties is not a waste of time, because I get enough food, better health and income					
3	I am highly motivated to learn best practices from the cassava Innovation Platform					
4	The Innovation Platform approach should be adopted by all farmers					
5	Providing feedback to other actors in my cassava IP is important					
Practices						
1	I prepare my gardens in time to take advantage of the first rains, source seed from certified sources, plant cassava and other crops in rows and weed in time					
2	I use domestic residue and animal waste to fertilize my land, and carry out all recommended agronomic practices					
3	I have increased cropland under cassava production					
4	I know how to add value to my cassava and I know the market where to sell my cassava seed, fresh roots and products					
5	I frequently provide honest feedback to other actors in my cassava IP					

Section 16C: AIS REPLICABILITY ASSESSMENT

#	**Sustainability measure**	**Response**	
1	Do u interact and share knowledge with members outside your cassava AIP? 1= Yes, 2=No		
2	Have outside members paid learning visits to your cassava AIP? 1= Yes, 2=No		
3	Are there any plans to start other AIP initiatives elsewhere that you know? 1= Yes, 2=No		

Section 16D: AIS SUSTAINABILITY ASSESSMENT

#	Sustainability measure	Response	
1	Will you continue in the AIP next year? 1= Yes, 2=No		
2	How much money did you contribute to your AIP the last year? (2015)		
3	How much are you willing to pay per year as membership fees to remain a member of the AIP?		
4	Rate your confidence in your AIP leaders: 1=Highly Trust, 2=Trust, 3=Undecided, 4=Don't trust, 5=Don't trust them		
5.	Do you have a collective future vision and targets for your AIP? 1=Yes, 2=No		
6	Do the local government authorities support your AIP? 1=Yes, 2=No		

Section 17: PERCEPTION STUDY QUESTION

State your ranking on each of the items listed below by ticking (√):

Criteria	Item	5= Very satisfied	4= Satisfied	3= Moderately Satisfied	2= Dissatisfied	1= Very Dissatisfied	Main Reason for ranking-Summarize reason
Crop performance in terms of YIELD	Local traditional cassava varieties						
	Modern Improved cassava varieties						
Seed access channel	Farmer-to-farmer or farmer saved planting materials						
	Government (NAADS, NARO)						
	Donors and not for Profit organization to farmer groups						
	Cassava seed entrepreneurs' distribution						
Institutional factors	Effectiveness of the current seed inspection and certification mechanisms						
	Access to credit services						
	Access to extension services						
	Market performance						
Trust		**5=Highly trusted**	**4= Trusted**	**3= Moderately trusted**	**2=Not trusted**	**1=Not trusted at all**	
Trust in seed access channel in terms of variety attributes, heath safety and hope of better yields	Farmer-to-farmer or farmer saved planting materials						
	Government (NAADS, NARO)						
	Donors and NGOs to farmer groups						
	CSEs channel						

Section 17: PERCEPTION STUDY QUESTION

State your ranking on each of the items listed below by ticking (√):

General agricultural challenges		**5=Very severe**	**4= Severe**	**3= Moderately severe**	**2=Not severe**	**1=Not sever at all**
	Lack of quality seeds					
	Lack of improved varieties					
	High cost of seeds					
	Poor roads					
	Poor transport means					
	Labor shortage					
	Lack of mechanization					
	Droughts					
	Lack of value addition technology					
	Lack of reliable markets					
	Low prices for cassava products					
	Insufficient extension services					
	Lack of affordable credit					
	List any specific comments here	**5=Very severe**	**4= Severe**	**3= Moderately severe**	**2=Not severe**	**1=Not sever at all**
Residual LRA war effects on agriculture	1. Land wrangles 2. Migration increased land prices **RECORD STATEMETS IN FORM OF QUOTES OVERLEAF**					
		5=Highly resilient	**4= Resilient**	**3= Moderately resilient**	**2=Not resilient**	**1=Not resilient at all**
Cassava adaptability to climate change (in prolonged rains and droughts)						
		5=Highly improved	**4= Improved**	**3= Moderately improved**	**2=Not improved**	**1=Declined**
Household welfare status as compared to pre-adoption days						

Section 18: HOUSEHOLD CONSUMPTION EXPENDITURE
Section 18A: Number of household members present
On average, how many people were present in the last 7 days? In this section children are defined as less than 18 years.

Household Members				**Visitors**			
Male adults	Female adults	Male children	Female children	Male adults	Female adults	Male children	Female children

Part 18B: Food, Beverage, and Tobacco (During the Last 7 Days)

Item Description	**Code**	Did you consume [ITEM] 1= Yes 2= No	How many days was [ITEM] consumed out of the last 7 days?	Unit of Qty **(See code sheet for units**)	Food Purchases consumed				Consumption out of **home produce**		Received in-kind/Free		Market Price	Farm gate price
					Consumed at home		Consumed away from home							
					Kgs/ Ltrs	Total Value	Kgs/ Ltrs	Total Value	Kgs/ Ltrs	Total Value	Kgs /Ltrs	Total Value		
1	**2**	**3A**	**3B**	**3C**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Matooke	1													
Sweet Potatoes	2													
Cassava (Fresh)	3													
Cassava (Dry/ Flour)	4													
Irish Potatoes	5													
Rice	6													
Maize (grains, Cobs, Flour)	7													
Bread	8													
Millet	9													
Sorghum	10													
Meat (Beef, goat, pork, hen)	11													
Fish	12													
Eggs	13													
Fresh Milk	14													
Infant Formula Foods	15													
Oils ghee, butter	16													
Honey	17													

Section 18B cont'd: Food, Beverage, and Tobacco (During the Last 7 Days)

Item Description	**Code**	Did you consume [ITEM] 1= Yes 2= No	How many days was [ITEM] consumed out of the last 7 days?	Unit of Qty **(See code sheet for units)**	Food Purchases consumed: Consumed at home		Food Purchases consumed: Consumed away from home		Consumption out of **home produce**		Received in-kind/Free		Market Price	Farm gate price
					Kgs/ Ltrs	Total Value	Kgs/ Ltrs	Total Value	Kgs/ Ltrs	Total Value	Kgs /Ltrs	Total Value		
1	**2**	**3A**	**3B**	**3C**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Fruits	18													
Vegetables	19													
Legumes	20													
Simsim	21													
Sugar	22													
Tea	23													
Coffee	24													
Salt	25													
Soda*, Beer*, juice	26													
Cigarettes & Tobacco	27													
Expenditure in Restaurants on:														
1. Food	28													
2. Soda, water, beer,	29													

*** Sodas and Beers to be recorded here are those that are not taken with food in restaurants.**

Section 18B Cont'd: Food Fortification

CHECK WHETHER THE HOUSEHOLD CONSUMED ANY MAIZE FLOUR, SUGAR, SALT OR COOKING OIL DURING THE LAST 7 DAYS

Item Description	Code	Did the household consume [ITEM] 1= Yes 2= No	Is the [ITEM] fortified? 1= Yes 2= No 3= Don't Know CHECK FOR FORTIFICATION LOGO OR SHOW SAMPLE TO RESPONDENT	What Brand of MAIZE FLOUR was consumed? SPECIFY		What brand of COOKING OIL was consumed?		What brand of SUGAR was consumed?		What brand of SALT was consumed?	
1	**2**	**14**	**15**	**16A**	**16B**	**17A**	**17B**	**18A**	**18B**	**19A**	**19B**
Maize flour	30										
Cooking oil	31										
Sugar	32										
Salt	33										

Section 18 C: Non-Durable Goods and Frequently Purchased Services (During the last 30 days)

Item Description	**Code**	**Unit of Quantity**	**Purchases**		**Home produced**		**Received in-kind/Free**		**Unit Price**
			Qty	**Value**	**Qty**	**Value**	**Qty**	**Value**	
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Rent of rented house/Fuel/power									
Rent of rented house	34								
Imputed rent of owned house	35								
Imputed rent of free house	36								
Maintenance and repair expenses	37								
Water	38								
Electricity	39								
Generators/lawn mower fuels	40								
Paraffin (Kerosene)	41								
Charcoal & Firewood	42								
Non-durable and Personal Goods									
Match boxes	43								
Soap (Washing & Bathing)	44								
Cosmetics	45								
Handbags, travel bags etc.	46								
Batteries (Dry cells)	47								
Newspapers & Magazines	48								

Transport & communication									
Transport costs (Tires, tubes, spares, fuel, taxi, bus, Boda-boda etc.)	49								
Air time for owned fixed/ mobile phones	50								
Expenditure on phones not owned	51								

Section 18 C cont'd: Non-Durable Goods and Frequently Purchased Services (During the last 30 days)

Item Description	Code	Unit of Quantity	Purchases		Home produced		Received in-kind/Free		Unit Price
			Qty	Value	Qty	Value	Qty	Value	
1	2	3	4	5	6	7	8	9	10
Health and Medical Care									
Medical Expenses	52								
Traditional Doctors fees/ medicines	53								
Other services									
Sports, theaters, etc.	54								
Dry Cleaning and Laundry	55								
Houseboys/ girls, Shamba boys etc.	56								
Barber and Beauty Shops	57								
Expenses in hotels, lodging, etc.	58								

Section 18 D: Semi-Durable Goods and Durable Goods and Service (During the last 365 days [LAST ONE YEAR of 2015])

Item Description	Code	Purchases	Received in-kind/Free
		Value (UGX)	Value (UGX)
1	2	3	5
Clothing and Footwear			
Clothing (Men, women, children (excluding school uniforms))	59		
Shoes (Footwear) [Men, women, children)	60		
Furniture, Carpet, Furnishing etc.			
Furniture Items (Beds, tables, chairs, Carpets, mats, etc.)	61		
Curtains, Bed sheets, Blankets, mattresses etc.	62		
Household Appliances and Equipment			
Electric gadgets (iron/ Kettles, TV, radio etc.)	63		
Charcoal and Kerosene Stoves	64		
Bicycles	65		
Motor-vehicles	66		

Motor cycles	67		
Computers for household use	68		
Phone Handsets (both fixed and mobile)	69		
Jewelry, Watches, etc.	70		

Section 18D cont'd: Semi-Durable Goods and Durable Goods and Service (During the last 365 days) [LAST ONE YEAR-2015])

Item Description	**Code**	**Purchases**	**Received in-kind/Free**
		Value (UGX)	**Value (UGX)**
1	**2**	**3**	**5**
Glass/ Table ware, Utensils, etc.			
Metallic & Plastic utensils (plates, cups, basins, Jerry cans, buckets)	71		
Electric Switches, plugs, cables, etc.	72		
Education			
Fees and scholastic materials	73		
Services Not elsewhere Specified			
Expenditure on household functions	74		
Insurance Premiums	75		

Section 18E: Non-consumption Expenditure

Item description	**Code**	**Value (During the last 365 days)** (UGX)
1	**2**	**3**
Taxes (All including market dues)	76	
Pension and social security payments	77	
Remittances, gifts, and other transfers	78	
Funerals and other social functions	79	
Interest on loans & routine subscriptions	80	