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Technological and Managerial Gaps in the Adoption of Improved Groundnut Seed Varieties in Uganda

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Technological and Managerial Gaps in the Adoption of Improved Groundnut Seed Varieties in Uganda

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CHAPTER ONE: INTRODUCTION

1.1 Background

At the end of 2015, the official deadline for the United Nations' Millennium Development Goals (MDGs), the Food and Agricultural Organization (FAO) reported that the *undernourished* proportion[1] of the developing world population had fallen from 23.3 percent in 1990, to 12.9 percent, fundamentally improving the welfare of 216 million people worldwide (FAO, IFAD, & WFP, 2015). Despite these positive outcomes, improvement is advancing at an increasingly slower pace and is potentially in danger of trend reversal as the effects of climate change become more serious. Today, about one in nine people (approximately 795 million[2]), largely concentrated in Sub-Saharan Africa (SSA) and Southeast Asia, are still undernourished; a vulnerable population that is likely to grow unless efficient adaptation and mitigation strategies are adopted.

In its most recent report, the Intergovernmental Panel on Climate Change (IPCC), representing 195 member countries and thousands of scientists, explicitly warns of decreases in crop production and water availability following extreme weather events such as heat waves and heavy precipitation (IPCC Core Writing Team, Pachauri, & Meyer, 2014). Additional global risk projections include declining work productivity and increased morbidity and mortality as a result of dehydration and heat exhaustion; a particular risk to agricultural workers who labor outside and rural households that walk long hours to collect water and wood or access local markets. There is further high consensus among the authors of the report that within communities dependent on agriculture and pastoralism, that there will be an uptick in violent conflict as communities vie for

[1] Undernutrition is a population measure of the number of persons not consuming enough food to live a healthy and active life.
[2] Five million of the 795 million people referenced live in developed countries.

diminishing access to resources (FAO et al., 2015). This is an outcome that persistently characterizes many of the countries where food insecurity continues to persist.

The most recent manifestation of El Niño, the warm phase of the cyclical El Niño–Southern Oscillation (ENSO) phenomenon, offers insight into how devastating extreme shocks in weather patterns can be, with shifts in wind and temperature patterns resulting in extreme rain and flooding in some parts of the world, drought in others (NOAA, 2016). According to the Famine Early Warning Systems Network, short-term shifts in climatic conditions as a result of El Niño have already resulted in delayed rains, thus distorting the agricultural planting season, and caused severe droughts.

With 2016 likely to be one of the driest growing seasons on record, it is expected that farmers will experience several consecutive years of poor crop production. Within the past six months, diminished crop yields have inflated food prices, including staples, and substantial food aid is anticipated to be required in the coming year. Several countries have declared drought emergencies and 2.5 million people are classified as being in crisis just within the South Eastern region of Africa (FEWS, 2016).

Though some countries have initiated development of collaborative forecasting systems that would allow scientists and farmers to communicate regarding adjustments to timing of planting and crop choice, this level of sophistication can safely be assumed to be beyond the abilities of many developing countries (Hansen, Mason, Sun, & Tall, 2011). Indeed, efforts towards promoting modern farming methods (e.g. the Green Revolution) have largely failed in countries that are both most susceptible to climate change and are already food insecure. One option offered by agricultural scientists is to promote adoption of locally popular and economically viable crop varieties, with selected characteristics such as drought-tolerance and pest resistance in

order to enhance production and yields. These seeds, known as *improved varieties* (IV) are not reliant on expensive agrochemicals and are suited to local agro-ecological zones. IVs are typically bred by taking into account that much of agriculture in SSA is rain-fed and relies largely on simple tools such as hoes and family labor.

Over the last decade, the international community has committed upwards of a billion dollars globally to the development and distribution of *climate smart agriculture* (CSA) that has successfully demonstrated strong yield returns on field stations overseen by government research centers and organizations such as the CGIAR members. What is highly uneven however, is the understanding of how smallholder farmers (as the intended primary consumers of IVs), are responding to this technology, both through rates of adoption and their ability to obtain similar production gains compared to agricultural scientists. In short, production of potential technologies has been substantial but there is still a lack of insight into which of these technologies are best suited to alleviate future and current pressures on food security.

As general practice, when smallholder farmers seek to increase production, they frequently do so by expanding the land that they cultivate (i.e. at the *extensive margin*) as opposed to using improved technologies while keeping the land constant (i.e. at the *intensive margin*). In an effort to slow down the expansion of cultivated land, which results in the clearing of forests and perpetuates climate change, it will be necessary for scientists to breed IVs that will allow for productivity gains on the intensive margin without requiring the acquisition of additional expensive technologies or agronomic practices that have been rejected in the past.

Agricultural technologies must be contextually appropriate in order for them to have any impact. Regardless of what is technically possible in drought-prone environments, without the

buy-in of farmers who are willing to adopt IVs, policymakers should understand that such strategies are not suitable.

With this two-fold interest in crops that are already suited to arid regions (thus likely to be more resilient to climate change) and are locally popular (meaning that societies have a vested interest in their cultivation) the interest of donor organizations such as USAID has naturally turned to legumes and pulses including groundnuts, beans, lentils and peas. Indeed, 2016 has been declared the International Year of the Pulse by the United Nations (FAO, 2015), in recognition of their global popularity, nutritional benefits, and economic potential. Furthermore, legumes, even *traditional varieties* (i.e. locally found and widely used plant breeds), frequently have the advantage of doing well in drought-prone environments compared not only to fruits and vegetables but also to 'thirsty' staples such as maize.

Guided by the motivation to assess the potential of promoting crop varieties suited for the changing climate by societies likely to be most affected, this study considers the potential for adoption of improved groundnut varieties in Uganda.

1.2 Problem Statement and Objectives

Groundnuts (*Arachis hypogaea L.*) are a globally grown and consumed oilseed legume across both developed and developing countries, the largest producers being China, India and the USA. Cultivated under both modern commercial and rain-fed smallholder conditions, groundnuts are recognized as a popular protein and also as a source for vegetable oil (similar to soybean and sunflower seed) (Freman et al., 1999). The commercial export potential of groundnuts is large, but volatile, as groundnuts must face price competition from other oilseeds (namely soybean) in addition to concerns of aflatoxin contamination. For smallholder farmers this crop is popular,

especially in the African continent where interest has been largely driven by population growth (Freman et al., 1999).

The suitability of groundnuts is high given its relatively low-input requirements to achieve a moderate yield and its spillover applications. Groundnut residues can serve as animal feed and more importantly, as an intercropped ground cover crop that provides nitrogen fixing to nutritionally depleted soils, thus offering a natural alternative to costly fertilizers. Within communities, groundnuts offer smallholders some cash income that is important for welfare expenditures such as their children's education, health, etc., making it an important food security crop (Obuo, Nangoti, Nalyongo, Akurut-Akol, & Otutu, 2004).

Though groundnuts can prove to be high yielding and profitable under modern production systems while also providing sufficiently moderate yields under subsistence and smallholder production systems, productivity is observed to be either stagnant or declining in developing countries. One of the major threats to groundnut productivity, is the aphid transmitted groundnut rosette virus (GRV) which has the capacity to blight affect plots, either eliminating or highly diminishing their production (Davies & Kasule, 1964; Mugisha, Lwasa, & Mausch, 2014). The development of pest and drought-resistant *improved groundnut varieties* (IGV) by national breeders in partnership with research outfits such as ICRISAT have offered highly promising on station yields, but information regarding adoption and productivity implications for the farmers themselves is limited.

Efforts to promote the development of IGVs in Uganda are strong, as demonstrated by USAID's Feed the Future program, which supports a collaborative partnership between Ugandan scientists and U.S. researchers under its Feed the Future Innovation Lab for Collaborative Research on Peanut Productivity and Mycotoxin Control (PMIL). Given that past studies have focused either

on research station yields or in areas where farmers are likely to be the most productive, this study offers the next step in impact assessment by considering adoption of IGVs at the national level and insights into potential productivity gains when technology is in the hands of representative farmers.

In an effort to discern the suitability of IGVs for widespread adoption in support of food security objectives, this study considers both the IGV institutional environment, offering insights into the factors likely responsible for gaps in reported adoption rates, and the outcomes of groundnut production as it relates to the likelihood of widespread farmer buy-in.

The key issue in this thesis is to examine the potential of IGVs to improve yields and production while measuring the managerial capacity of adopting farmers compared to peer farmers that utilize traditional varieties. This study employs propensity score matching (PSM) combined with stochastic production frontier analysis (SPF). PSM is utilized to mitigate selection biases from observable variables through which a logit model is used to generate propensity scores for all farmers based on their predicted probability of adopting IGVs. The SPF for groundnut farmers, improved seed Adopters, and Non-Adopters is modeled and technical efficiency is estimated.

Two studies that have considered adoption of IGVs in Uganda have reported relatively high rates of adoption, 59 percent and 58 percent respectively (B Shiferaw, Muricho, Okello, Kebede, & Okecho, 2010; Tanellari, Kostandini, Bonabana-Wabbi, & Murray, 2014). These studies focus on sub-counties where groundnut production is strong, but do not address potential structural differences within these communities that might help promote adoption of IGVs. National level data from both ICRISAT and this study indicate that a sampling strategy that focuses specifically on commercialized groundnut communities may have the potential of overestimating adoption at a magnitude of 500 percent. A contribution of this study is to consider institutional attributes that influence this gap.

This thesis utilizes World Bank data from the Living Standards Measurement Survey-Integrated Surveys on Agriculture (LSMS-ISA), collected in coordination with the Ugandan Bureau of Statistics. These are panel data sets containing exhaustive information regarding household and community indicators. A benefit of using LSMS is that it responds to calls for reform in developing country data collection (Jerven, 2013; Sandefur & Glassman, 2015) through its commitment to best practices as well as its secured long-term financial support. Contributions of this study will include identification of missing or inadequate information relevant to adoption and productivity analysis in support of continued efforts to improve LSMS quality and expand potential application.

1.3 Organization of Thesis

The remainder of the thesis is organized as follows. Chapter Two provides an introduction to Uganda and a background of the IGV breeding program. A breakdown of the agro-input industry as it pertains to groundnuts is offered to assist the reader in understanding the environment of adoption at the national level. Chapter Three contains a review of the relevant methodological literature and explains the data and econometric model employed. Chapter Four discusses the results and Chapter Five provides a summary and recommendations.

CHAPTER TWO: COUNTRY AND CROP BACKGROUND

2.1 Country Background

Uganda is typical of SSA countries in that agriculture plays a substantial role in its economy. The number of people participating in agriculture has surged even as the labor force participation has fallen following migration of rural citizens into urban areas. From 1999 to 2014, the proportion of Ugandans working in agriculture dropped from 80.6 to 72.3 percent (as seen in Figure 1); but, due to population expansion, this has meant a 50 percent increase in the number of agricultural workers from 8.24 million to 12.54 (FAOSTAT, 2015). Total agricultural production has increased, accompanied by steady declines and stagnation in productivity over the past 15 years. Indeed, gains in production are attributed to an expansion of cultivated land (Kraybill, Bashaasha, & Betz, 2012), a factor likely contributing to Uganda having one of the highest rates of soil depletion in SSA (Pender, Jagger, Nkonya, & Sserunkuuma, 2004). From 1990 to 2015, undernutrition has increased from 23 to 25 percent, a negative trend (shown in Figure 1) that is not reflective of either East Africa or the SSA region at large (FAO et al., 2015). With undernutrition presenting as a serious problem, current efforts by government research centers (e.g., USAID, and the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)) to promote the production of groundnuts offers a unique opportunity to tackle food security related issues.

Groundnuts, also known as peanuts, are touted as having the highest return for labor compared to other food crops (Thuo et al., 2014). Far from being a niche crop, they are widely grown across the world for their economic, nutritional, and taste value. In Uganda, they are the second most popular legume after beans (Mugisha, Ogwal-o, Ekere, & Ekiyar, 2005) and are highly regarded given that they can be grown in both farming seasons, and can also be stored to avoid price fluctuations (Oleru, Semana, Bua, Mutimba, & Obaa, 2005). The consumption of

groundnuts, eaten roasted, boiled, or, as is most popular in Uganda, in the form of a sauce, offers high protein and fat content that can be considered as an increasingly affordable substitute for expensive animal proteins (D. Okello, Biruma, & Deom, 2013). The importance of groundnut sauce to the Ugandan diet can be easily observed by considering that few eateries, if any, will operate without preparing 'g-nut sauce' on a daily basis.

2.2 Groundnut Production in Uganda

Though groundnut cultivation permeates the agricultural environment in Uganda as well as much of East and Southern Africa, yields and total area under production have been decreasing over the past 30 years (as seen in Table 1 and 2) (Freman et al., 1999; Okello et al., 2013). As a result, extensive research has been undertaken to determine the biotic and abiotic constraints to groundnut production. Major concerns warranting technological intervention include: erratic rainfall, disease in the form of groundnut rosette virus (GRV) and leaf spot minor, pests such as aphids, thrips and termites, as well as aflatoxin contamination (Okello et al., 2013). The effects of these constraints vary from blighting groundnut yields completely, to reducing size and quality. Aflatoxin poses a particular concern in that it is a carcinogenic compound toxic to both humans and livestock. The presence and even potential of aflatoxin contamination has had serious effects on the ability to market groundnuts for export (Babu, Subrahmanyam, Chiyembekeza, & Ng'Ongola, 1994).

Under the environment of intensive guerilla fighting, forced displacement, and the consequent lack of access to land for many in the Northern region, the spillovers of recent prolonged conflict and instability can also be seen as factors undermining production (Okello, Biruma, Anguria, Akello, & Deom, 2012). Production area gradually fell in the early 1970s, but then dramatically collapsed starting in 1979. The Luwero Triangle War (1980 – 1985) led to the

destruction of the Seed Scheme Headquarters. The country's only operating seed company, the Uganda Seed Project, was shut down after being looted, and research along with all quality control activities ceased. While there was some recovery in the later 1980s, the 1990s showed only 60 percent of 1970s production levels, before the country plunged into another civil war yet again; this one lasting for about twenty years, and involving the entire northern region.

In the early 1980s, groundnut production in developing countries made up 80 percent of global production, with 67 percent of the total coming from rain-fed semi-arid conditions. Average yields of 700 – 800 kg/ha in developing countries were low compared to developed country yields of 2,500 kg/ha (Gibbons, 1980). In an effort to combat early concerns of biotic stress factors such as GRV and leaf spot minor, in 1982 the South African Development Coordination Conference (SDCC), comprised of various heads of state, invited ICRISAT to establish a research center in Malawi (Hildebrand, Bock, & Nigam, 1990). The program, known as the Grain Legume Improvement Program (GLIP), was established with the intention of promoting yields for smallholder farmers and therefore oriented its plant breeding approach to maintain low-input practices consistent with resource scarce conditions.

ICRISAT's base in Malawi is to this day positioned to serve as the regional base for information diffusion on legume technologies. Over time, ICRISAT has forged strong partnerships with the Malawian government and the National Smallholder Farmers Association of Malawi (NASFAM). Notable collaborations include the creation of the Malawi Seed Industry Development Programme in 2008 to support the government's input subsidy programs, the promotion of farmer field days, and the development of inexpensive aflatoxin kits to help potential exporters meet European Union regulations.

As part of their general objectives to promote productivity through the semi-arid tropics, ICRISAT created a germplasm bank that is accessible to national research centers. Uganda's National Agricultural Research Organization (NARO), the primary groundnut research institution, has made use of this partnership to obtain improved genetic material through which they adapt varieties. As a primary focus of their research, NARO adapts germplasm from ICRISAT to Uganda's agro-climatic conditions. Most of this research takes place at the NARO center in Serere district in the Eastern region, along with other sites specifically selected for being GRV hotspots.

ICRISAT and NARO's collaboration has developed numerous varieties of IGVs, the majority of which possess drought tolerance as well as disease and pest resistance attributes. Variations include characteristics that shorten maturity periods, influence oil and sweetness content, in addition to other characteristics preferred by farmers and households. The color of groundnuts is a particularly important attribute with red groundnuts being popular with households in the North and East for the color they provide to g-nut sauce. Other relevant characteristics include size and whether the groundnut variety is spreading or erect.[3] Research station yields are estimated at 3,500 kg/ha for IGVs while maximum yields for the popular traditional variety, Red Beauty, are around 2,500/ha (Okello et al., 2013).

These gains are notable given the biotic factors that prey upon groundnut plants. When GRV has attacked a plant, it can be observed by its highly diminished stature. The effect of GRV can be to wipe out all production for affected plants. Leafspot Minor can be observed by brown spots, some ringed by a yellow halo, with severely affected plants losing many or all of their leaves.

[3] Plants considered to be spreading are lower to the ground and appear to form small bushes. They produce more groundnut pods per plant but are also harder and more time intensive to harvest. Erect plants are taller, take up less space, and produce fewer pods, but because of their physiology, are easier to harvest by hand. Perceptions of yield outcomes between these plants may differ given the managerial capacity of the farmer to effectively harvest. With spreading plants, the danger exists that pods may be left in the ground or are time consuming to access.

Plants infected by Leafspot Minor will experience diminished yields. Scientists have noted that this disease can be mistaken by farmers for a mature plant, ready for harvesting, and therefore bears the risk of not being detected or treated.

Uganda's groundnut research program, separate from ICRISAT, was created in 1930, with studies on GRV starting in 1949. Red Beauty, the most popular traditional variety today was developed in the 1950s and introduced in 1958, leading to the formation of the formal breeding program in 1963. Characteristics that have been identified over time for their economic value include the mutually exclusive attributes of oil content (to produce vegetable oil) or sweetness (for confectionary purposes). More general breeding efforts have focused on pest resistance, early maturing characteristics and adaptability to dry climatic conditions (Okello et al., 2012).

To date, four out of 14 IGVs developed by the modern breeding program have been released in Uganda. These varieties are Serenut 1-4, with Serenut 5 just having been registered and 6 still in the multiplication phase. Of the released varieties, Serenut 2 and 4, both tan, are the most popular improved varieties. Together they have been in the market a modest amount of time, with Serenut 2 being released in 1998 (same as Serenut 1, a red variety) and Serenut 4 being released in 2002 (as was Serenut 3, also red).

2.3 IGV Adoption Literature in Uganda

Of the few studies available, researchers have targeted communities where groundnut cultivation is popular. Considering farmers from the Eastern and Northern region, with a focus on groundnut growing sub-counties, Shiferaw et al. (2010) found high adoption rates at 59 percent, with approximately 62 percent of groundnut areas under IGV cultivation. Also working in the Eastern region, Tanellari et al. (2014) found similar adoption rates of 58 percent while using a minimum threshold of fifty percent cultivation of IGVs in order to qualify as adoption. Tanellari

et al. note that the Teso sub-region in Eastern Uganda had the highest adoption rate, similar to Shiferaw et al.'s findings, and suggest that this is likely due to the location of the national groundnut breeding center in Serere, a district within Teso.

Tanellari et al. also find gender differences in adoption, with female heads of household being less likely to adopt. A follow-up study using the same dataset as Shiferaw et al., assessed the welfare effects of IGV adoption and found evidence to consider IGVs as a potential pathway out of poverty, with an additional $496 per hectare being generated on average compared to Non-Adopters and the largest impacts being felt by smaller farms (Kassie, Shiferaw, & Muricho, 2011). These adoption rates differ widely compared to data reported by ICRISAT (Bantilan, Deb, & Nigam, 1999), indicating an unlikely 500 percent increase in IGV adoption. These estimates also differ widely compared to the LSMS data used in this study, which indicates adoption rates comparable to the ICRISAT data at approximately ten percent. Of note is that both the ICRISAT and LSMS datasets operate at the national levels, compared to Shiferaw et al. and Tanellari et al. that only consider farmers in popular groundnut communities.

It is relevant to acknowledge the difference between nationally representative communities and those that have been specifically sampled for being major 'groundnut communities'. In the case of the latter, it is probable that communities are structurally different in terms of opportunities for commercial benefits as well as enhanced access to information pathways specifically relevant to groundnut production. For the purposes of considering the potential for adoption for smallholder households throughout Uganda, it is important that sampling take place both inside and outside of such hubs.

2.4 Adoption in Developing Country Agriculture

Writing on their theory of induced institutional innovation, Hayami and Ruttan (1985, p. xix) argue that the "capacity to develop technology consistent with resource endowments [is] the single most important variable which explains the growth of agricultural productivity of nations." And yet, in his guide to developing successful seed programs, CGIAR seed unit coordinator Johnson Douglas (1980) notes that "[n]o benefits result from making good quality seed available unless farmers obtain and plant seed of improved varieties. Too often seed programs focus on producing and processing seed and neglect factors that contribute to seed use" (p. 145).

Much has been written about how the adoption of Green Revolution technologies proved successful in regions such as East Asia, India and Latin America, yet made a less than marginal impact in SSA, leaving farmers to continue as they had in decades before (Eicher, 2009; Fan, Johnson, Saurkar, & Makombe, 2008; Pretty, Toulmin, & Williams, 2011; Sahn, 2015). As policymakers continue their urging for the promotion of productive agricultural inputs, it is useful to consider the trajectory of maize hybrids in SSA, given this crop's role as the most popular staple across the region. Studies assessing the rate of return of investment in maize research in SSA have demonstrated that their impact can be high, with Kenya, Uganda, Malawi, Zambia, Zimbabwe and Mali, all experiencing returns over 40 percent over several decades (Byerlee & Eicher, 1997). Evidence also indicates, however, that well into the mid-1990s, there were several countries where the adoption of hybrids was effectively non-existent.

That the utilization of inputs across SSA is low is an observation that has been documented in many studies, yet there is little commentary regarding its unevenness, with there being wide

disparities[4] in the uptake of inputs such as hybrid seeds between countries, even those that neighbor each other and may share similar agro-ecological and cultural traits (Amponsah & Paliwal, 2015).

In order for adoption to occur, the utility a farmer expects to achieve as a result of adoption should be greater than the utility a farmer will achieve if they do not adopt. How these perceptions of utility are derived however, is a murky relationship of both socio-economic factors and farmer characteristics, some of which may be observable, others not.

Recent cross-country comparisons are scant, yet certain essential truths have endured about necessary conditions required adoption to take place. When describing the work of Shultz (1964), Hayami and Ruttan (1985, p. 2) write that "[i]nvestment in such activities such as agricultural research, leading to the supply of new inputs, and in the education of the farm people who are to use the new inputs will provide the basis for technical change and productivity growth in agriculture." Establishing this progression is highly relevant given that the steps of creating a supply of the new inputs, and the education of consumers is not necessarily natural or given.

Researchers serve a role in the domestic seed market, by providing what is called *breeder seed*, i.e. the highest quality genetic material that is later used for multiplication efforts by private or government seed suppliers and is consequently very costly. While an entire technical literature exists on the necessary institutions required for an effective seed sector, it should be noted that agricultural policy needs to play a strong role in promoting both seed supply and certification in order to control quality and provide farmers with confidence about the reliability of IV inputs.

When gaps exist in the availability of reliable seed, either due to the absence of proximate supply or to limited trust in the quality of the input supplier, farmers will be prevented from purchasing seed. When a new quality product is available on the domestic market, adoption rates

[4] See Byerlee and Eicher (1997, p. 130) for details regarding adoption of hybrids and improved pollination varieties across 20 SSA countries.

will be affected adversely in areas where obtaining the seed would require excessive transportation costs or overcoming significant risk aversion following previously negative experiences.

Farmers will additionally need to be made aware of the existence of the newly developed technology. Diagne and Demont (2007) refer to *non-exposure bias*, explaining that if a farmer has not been exposed to a particular available product, they cannot possibly adopt it even if they might have done so otherwise. Exposure can refer to either the diffusion of information, or can be extended to an understanding of its characteristics and performance, likely through social networks, demonstration plots, or contact with extension workers. For the purpose of understanding the necessary conditions for adoption, both diffusion and exposure are highly relevant, especially in the context of weak agricultural institutions, though intensity of exposure, and its determinants, are what social scientists typically consider. The importance of estimating adoption conditional on exposure is being acknowledged in the field, with new studies starting to incorporate exposure into their models (Bekele Shiferaw, Kebede, Kassie, & Fisher, 2015; Simtowe, Asfaw, & Abate, 2016).

If a farmer does eventually adopt a new technology, it is relevant to consider whether the metric is satisfied either by a one-time usage, or if adoption can be understood as a continuous process of cost-benefit analysis, indicating the possibility of future rejection. Hayami and Ruttan (1985, p. 5) argue that "[any] stream of new technical inputs must be complemented by investments in general education to be consistent with the new growth potentials if the full productive potential of the new knowledge and the new inputs is to be realized." Indeed, if a farmer does not obtain yields comparable to those either expected, then continued adoption of new technologies is unlikely, especially if required usage requires additional costs.

The role of extension as an effective source of such education and exposure is a contentious one in the experience of many SSA countries (Cunguara & Moder, 2011; Davis et al., 2012; Feder, Anderson, Birner, & Deininger, 2010; Smale, Byerlee, & Jayne, 2011). This is the case, despite the fact that extension workers are acknowledged to be the major force behind the diffusion of maize. For example, in Kenya, in one of the most successful maize R&D programs, extension agents established 'tens of thousands' of demonstration plots which were critical in farmers' decisions to adopt (Byerlee and Eicher, 1997). Apart from demonstration farms, a common hierarchical approach to extension includes the Training and Visit system, whereby extension agents would thoroughly train a model farmer in particular communities, with the expectation that those farmers would then convey information to others in their communities.

Though there are large gains to be obtained from effective extension, implementation is a concern, especially with regard to sustainability in the face of insecure financing. With shrinking travel and facilitation budgets, the ability of extension agents to visit and directly liaise with farmers has also diminished. Indeed, an assessment by the World Bank of funded extension projects found that efforts to cut costs by using top down approaches have led to 'standard packages of recommendations' that fail to meet specific farmer needs. Additional issues included weak communication between extension agents and agricultural researchers, and ultimately the ability of extension agents to offer appropriate technological advise to farmers, especially small scale ones dwindled, as did their efficacy (World Bank, 1994).

Over the years, disruptions in research funding, poorly articulated research priorities, and mismanaged or absent linkages with policymakers, farmers, and agribusiness have contributed to the increasing isolation of national research centers from 'mainstream agricultural development' (Eicher, 1989). This is not to suggest that there has been some continual sense of dismal decline

without change across the SSA continent, but rather to acknowledge that the development of productive technologies in isolation is not sufficient to produce a suitable effect without complementary institutions.

Indeed, several countries have achieved substantial success in promoting agricultural technologies. There are also shifts in approaches where researchers are increasingly concerning themselves more with market preferences and developing technologies with smallholder growing systems in mind. However, without the fundamentals of a reliable seed sector, pathways of exposure, and educational institutions, farmers will be unlikely to have the opportunity to develop an assessment of their expected utility of adopting IGVs. Returns through high yielding adoption will require long-term crop-specific efforts (Byerlee & Eicher, 1997).

2.5 Agricultural Environment in Uganda

The NARO breeding program has been prolific, with 14 IGVs of varying attributes being produced since 1998 and achieving results of over 3,000 kg/ha (Okello, Monyo, Deom, Ininda, & Oloka, 2013) compared to research station yields of approximately 2,500 kg/ha for traditional varieties. Smallholders on the other hand typically produce around 1,000 kg/ha. With the successful development of value-added groundnut seeds, it is of interest for stakeholders to consider the institutional conditions required for the effective diffusion of IGV technologies in order to effectively promote their utilization.

Early research regarding adoption of IGVs is limited,[5] but does not appear to be representative of the national context or the average groundnut farmer. While it is typical for studies to find uneven results, it is highly unusual for the gap to be a 500 percent difference over a period of time as little as ten years in the absence of structural transformation.

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[5] Shiferaw et al. (2010) claims that that there had not been any work prior to their study.

Shiferaw et al. (2010) as well as Tanellari et al. (2014) focused largely on areas where groundnuts are commercially grown. In contrast, this study provides insight into dissimilarities that are understood to exist between the agricultural environment in the Eastern and Northern regions compared to the national context. It is within expectations for developing countries to have fragile institution environments that can distort information dissemination and access to inputs within the country itself. This is particularly relevant in the case of a post-conflict country such as Uganda. With this context, it is therefore useful to consider the necessary conditions for an effective seed system to operate in order to effectively interpret findings from various studies. As previously discussed, requirements include a reliable seed supply, exposure to information, as well as knowledge and implementation of sufficient management practices. The remainder of Chapter 2 is dedicated to assessing Uganda's institutional environment related to these three basic conditions.

2.5.1 Seed Sector

When considering the potential for the IGV seed sector in Uganda, it is critical to keep in mind two points: (1) that groundnut farmers have historically utilized saved and bartered seed instead of purchasing new seed; and (2) the major purpose for groundnut cultivation is domestic consumption and intercropping. As such, preferences are skewed towards consumption relevant attributes such as a taste and a vibrant red skin color and these preferences are highly entrenched.

The process of R&D requires that seed companies go through the effort of multiplication, quality control, marketing, and offering their own extension support. Private sector willingness to take on such investment will be directly related to perception of consumer demand. In effect, seed companies must make their own adoption decisions, which will be based on farmer likelihood of adoption. Points (1) and (2) are relevant here in that the costs of R&D for groundnut seeds may be

high for seed companies given that perception for consumer demand for seed is low compared to other more commercialized crops such as vegetables or maize.

In a study by NARO researchers, it was found that only a third of groundnut farmers purchased seeds from the market, with other sources including saved seeds, public institutions, NGOs, and neighbors (Okello et al., 2014). The study additionally pointed out that where NGOs were involved, they chose to source their seeds directly from research organizations such as NARO, citing their confidence in the reliability of the seed.

Reliability in the seed sector extends beyond groundnuts, and has been largely attributed to a ‘chronically weak’ regulatory framework that is acknowledged to be underfunded to the point of not carrying out basic inspection practices without ‘facilitation’ from the private sector or donors (Joughin, 2014). As a result, seed companies have become notorious for providing low-quality product. In addition, the seed regulatory framework is onerous, with large constraints on the development of new varieties by the private sector and foreign sourcing. This effectively prohibits seed companies from taking an active role in promoting seed products that may have more attractive qualities to consumers than what is currently being produced by NARO (Joughin, 2014).

2.5.2 Extension: NAADS

Finding a ‘best practice’ approach to extension in post-colonial and developing countries has been an ongoing policy challenge that suffers from deficits in institutional strength and resource allocation. Structural adjustment reforms aimed at reducing public sector spending have placed pressure on and undermined traditional public extension systems leading to decades of experimentation intended to cut costs by decentralizing, cost sharing, and privatizing government services. Interest in reforming the extension services is high, given concerns of weak researcher-

extension-farmer linkages, high levels of bureaucracy, and irresponsiveness to farmers' needs (Mubangizi, Mangheni, & Garforth, 2004). Following years of the Training and Visit system, 'contracting extension' is one option that has been promoted by the World Bank and attempted by the Government of Uganda (GoU) (Rivera & Alex, 2004).

In 2001, the GoU created the National Agricultural Advisory Services (NAADS) 'private service provider advisory system' whereby NAADS agents facilitate the provision of extension information by either NGOs, private individuals, or firms, on a contractual basis with farmer organizations. As such, NAADS would be a demand-driven, client oriented, and farmer-led agricultural advisory service delivery system. Practically, this meant that NAADS was intended to provide funds to farmer groups, who in turn would contribute a small portion of the costs, in order to engage the aforementioned service providers.

This system, theoretically, would result in tailored extension services to particular needs articulated by farmers without the costs of a national extension system that suffered from overlooking specific farmer interests. NAADS started out as a pilot in 24 sub-counties and gradually spread throughout the country. The intention was for the program to progress over 25 years, but instead, NAADS was recently 'overhauled', with civil servants being replaced by the military, mainly for the purpose of directly distributing inputs under President Museveni's personal project, Operation Wealth Creation.

Early experience with NAADS indicates that when the program came to a new district, it would initially work to sensitize local leadership and seek the assistance of NGOs to help mobilize farmers in the formation of farmer groups. Following the formation for groups, NAADS, again in collaboration with NGOs, would encourage farmers to identify several prioritized agricultural enterprises, which would go through a process of several referendums resulting in a sub-county

priority list. Sub-counties would then identify service providers and confer extension contracts subject to the availability of funds.

Despite the emphasis on participation, which has become a norm within the development jargon, the practice of meaningful participation is somewhat ambiguous. Implementation of priority ranking took on substantially diverse forms with some farmers having no opportunity to discuss initiatives, only to have a few individual farmers represent them at the sub-county level (Obaa, Mutimba, & Semana, 2005). In a case study of Mukono district, a rural sub-region with easy access to markets and Kampala, attendance to parish-level meetings was said to be poor owing to disillusionment with NAADS activities. Given that suggested priorities were assigned various weights in order to tally up a final score, farmers complained that selection criteria were obscure, a metric system that has been described by Obaa et al. (2005) as 'seriously flawed'. Mismatches between farmers' priorities and eventually chosen NAADS enterprises has been identified and reported elsewhere in the country as well (Oleru et al., 2005).

Disappointment arose when training programs were selected on topics that did not reflect farmers' priorities, or when they were told that there was no money available for inputs or facilitation of credit. Sentiments were offered asking what the point was on spending so much money on knowledge transfer when farmers were too poor to acquire the necessary inputs to implement it (Obaa et al., 2005).

Apart from poor prioritization, it has been argued that contract extension as a system is subject to flaws given that it could intensify weaknesses within the research-extension linkage and could also deteriorate quality of services as a result of profit orientation (Rivera et al., 2000; Schwartz, 1994). In a study of private service providers (PSP) in the Northern districts of Tororo and Arua, chosen for consideration since they were among the first to implement NAADS,

Mubangizi et al. found that PSPs were generally formally educated, but had limited working experience outside of NAADS. While a lack of experience can be a cause for concern regarding the quality of service provision, more so was the fact that there was no clear mechanism for quality assurance or technical backstopping. Difficulties in translating technical language into the local language reveals a lack of full familiarity with production knowledge.

In an assessment of approaches to information dissemination in Tororo, including but not limited to NAADS, it was found that of the farmers surveyed, just 12 percent were reached by NAADS, who mostly targeted the ‘average’ wealth category, compared to those identified as either ‘poor’ or ‘very poor’. By focusing on interaction with groups as opposed to specifically targeting households within coverage areas, the absence of village-level facilitators is keenly felt as many farmers that would likely have benefited are left out (Agwaru, Matsiko, & Delve, 2004).

NAADS has enjoyed a checkered reputation, with the most positive of assessments being that it substantially improved the availability of advisory services, but demonstrated little difference in yield outcomes (Benin et al., 2007). The gap between availability of advisory services and impact can be understood following reports that information availability is limited to a few agricultural enterprises that may not represent farmers’ interests. Opportunities for farmers to learn from NARO is expected to be limited given the minimal interaction between NAADS and NARO.

Even where farmers interests have been aligned with NAADS selected enterprises, it is within expectations that the effects of mismanagement will influence the impact of the NAADS program. Domestic sources, including mainstream newspapers, have accused NAADS of corruption, while external perspectives have described the extension agency as a system of patronage intended to mobilize votes for President Museveni (Joughin & Kjær, 2010).

In a follow-up study to Benin et al., new rounds of data collection found positive impacts from direct participation in NAADS on adoption of improved crop varieties,[6] with the strongest impacts found in the Eastern region as well as with those with the least access to financial services and markets (Benin et al., 2011).

2.5.3 Informal Institutions

NARO researchers and affiliates are reported to have been very active in IGV diffusion, though insights from NARO breeders indicate that much of the diffusion may be informal in nature. Kassie et al. write that there was a strong push by both NARO and NAADS to promote IGVs, but what is left unclear is the geographical coverage of these promotional activities. As might be expected, both Shiferaw et al. and Tanellari et al. found that the highest rates of adoption took place in direct proximity to the NARO groundnut research station.[7] This suggests that there is a connection between likelihood of adoption and location of NARO activities.

NARO researchers have supported this theory, writing that 20 percent of surveyed farmers sourced their seeds directly from NARO, compared to 9 percent from NAADS and 36 percent from the market (Okello et al., 2014). Results from this study also indicate that markets are most relevant in the Eastern region, with 57 percent of farmers buying their seed from private sector sources. NARO scientists have been proactive in creating networks with contract farmers for the purposes of seed multiplication. Several of these farmers, when interviewed, indicated that they expected large gains from filling gaps in the formal seed sector.

In the Northern region, NGOs are the major force behind diffusion, with aid organizations distributing agricultural inputs to former IDPs (Okello et al., 2014). Though it appears likely that

[6] It should be noted that improved varieties refers here to any crop variety bred with enhanced characteristics, and does not necessarily refer to IGVs.
[7] There are several NARO research centers across Uganda, each specializing on specific crops. The only groundnut related NARO center, is located in Serere.

farmers will adopt inputs that they have been given for free, interviews with some NGOs indicate that what can actually happen is that households will consume the seeds that they have been provided, and then will be unwilling to pay for additional inputs. A potential concern for the likelihood of adoption is that 42 percent of farmers surveyed reported not engaging in any pest-resistant practices despite widespread acknowledgement of GRV and its effects (Okello et al., 2014).

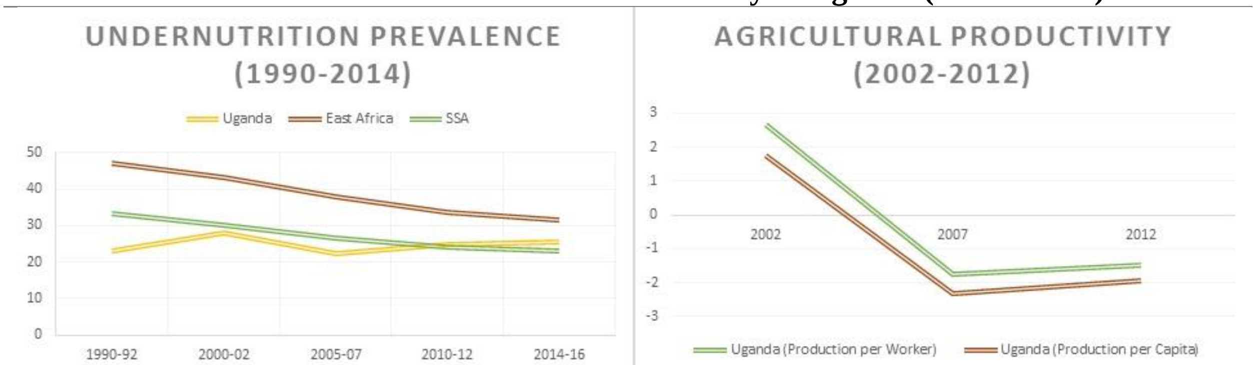
Given that farmers are accustomed to not purchasing seed, it is possible that the pest-resistant attributes of IGVs may not be attractive to the average smallholder farmer as assumed. Other attributes of IGVs such as drought resistance may also not be sufficiently attractive to farmers, following evidence from other countries that farmers aware of changing climate trends have not taken steps to adopt adaptation techniques (Fosu-Mensah, Vlek, & MacCarthy, 2012). This indicates that additional promotional campaigns may be required to encourage farmers to adopt IGVs.

2.6 Summary

The interest in IGVs is potentially large in Uganda where the legume is widely consumed and institutions exist for the development of high quality seed. The plant breeding program, spearheaded by NARO in collaboration with ICRISAT Malawi, has been prolific in its development of IGVs but measures of the real rate of adoption are mixed. The literature on Uganda's agricultural institutions provides evidence that the likelihood for adoption is not high in a nationwide context. Institutional weaknesses are evident as it relates to the availability of reliable seed, as well as opportunities for exposure to new technologies and beneficial management practices. Based on the literature detailing experiences of agro-input stakeholders, the relevance

of region as it relates to exposure and sensitization is hypothesized to have a strong impact on likelihood of adoption.

FIGURE 1: Undernutrition and Productivity in Uganda (1990 – 2014)



Source: (FAOSTAT, 2015)

TABLE 1: Uganda Groundnut Statistics (1977 – 1996)

	1994 – 1996 average	
Groundnut Area Harvested (000 Ha)	192	
Groundnut Production (000 T)	137	
Groundnut Yield (T / Ha)	0.7	
Groundnut Share In Total Oilseed Area (%)	31.7	
Groundnut Share In Total Oilseed Production (%)	41.1	
	1977 – 1986	*1967 – 1996*
Growth Rate Of Groundnut Area (% Per Year)	-2.7	1.8
Growth Rate Of Groundnut Production (% Per Year)	-4.3	0.3
Growth Rate Of Groundnut Yield (% Per Year)	-1.6	-1.5

Source: (Freman et al., 1999)

TABLE 2: Groundnut Yield Growth in Eastern and Southern Africa (1977 – 1999)			
Uganda	-0.2	*Sudan*	-0.1
Congo	0.7	*Malawi*	-0.5
Tanzania	0.4	*Zambia*	-1.9
Kenya	0.3	*Zimbabwe*	0.6

Source: (Bantilan et al., 1999)

CHAPTER THREE: METHODOLOGY AND DATA

3.1 Theoretical Framework

To evaluate the impact of IGVs on farmers in Uganda and their TE levels, this study implements a multi-step framework to first generate a group of comparable adopters and non-adopters and then estimate SPF models. The measured technological gap between Adopters and Non-Adopters and technical efficiency gaps for the two groups provide insights on policy options that could be implemented to promote agricultural productivity and income growth.

3.1.1 Introducing Production Frontiers

Modern approaches to productivity analysis, concerned with identifying trends in 'best practices', have their roots in the work of Farrell who proposed the production frontier as a method of obtaining various measuring efficiency measures.[8] *Technical efficiency* (TE) as defined by Farrell (1957, p. 254), can most easily be considered as the "success [of a firm] in producing as large as possible an output from a given set of inputs." Under this framework, if one were to consider a production isoquant, firms operating on the isoquant are technically efficient, whereas firms operating above the isoquant, are considered to be performing with varying degrees of inefficiency. How inefficient they are can be measured by their distance away from the production isoquant. Bravo-Ureta and Pinheiro (1993, p. 89) describe technical inefficiency as the "failure of attaining the highest possible level of output given inputs and technology."

Farrell argued that efficiency must also be considered in terms of the price of inputs, later referred to as *allocative efficiency*. Therefore, a firm is *economically efficient* if it operates along

[8] Farrell considered average productivity of labor to be so "so obviously unsatisfactory that one would not waste space discussing it" were it not for the "danger" of its popularity (1957, p. 263).

the production isoquant and utilizes the least cost input mix given prices.[9] Allocative efficiency has proved to be an underemployed metric, with those who address it acknowledging their difficulty in obtaining data on both input and output prices; a particular issue when many smallholder farmers obtain farm gate instead of market prices.[10] Additionally, many farmers will acquire inputs from neighbors or family members through bartering labor, other products, or social capital, which makes quantification of costs difficult. For groundnuts, a particular concern is that many farmers save seeds to replant the next year, and may only purchase a portion of what they plant.

While it is for future research to resolve these measurement issues, there is another element of allocative efficiency that should also be addressed. In addition to monetary costs for inputs such as seed or hired labor, the opportunity costs of land and household labor must also be factored in. Agricultural labor is typically carried out by women, who juggle the most labor-intensive tasks along with a multitude of other household obligations such as walking to acquire water, cooking (along with the attendant task of heating a coal stove), cleaning, taking care of children and other household members, selling goods at market days, and mandatory social engagements such as church, weddings, and funerals. Due to a lack of transportation, any errands that require leaving the house can consume a significant amount of one's time and therefore will be factored into potential labor hours.

To allow for heterogeneity within productive processes, such as described above, Farrell encouraged practitioners to employ an empirical approach based on the highest performers as

[9] Economic efficiency can be calculated as technical efficiency multiplied by allocative efficiency.
[10] The practice of farm gate prices are not only troublesome for determining allocative efficiency due to the limited data, but also because they frequently represent non-competitive markets as it is heavily prone to exploitation by wholesalers who have been known to trick the scales or demand savings premiums given their effective monopoly on transportation. As such, efficiency estimates would need to be interpreted as operating under highly imperfect conditions.

opposed to a likely unattainable theoretical approach as specified by industry experts. This is an important consideration in all frontier studies of efficiency.

Considerable progress has been made in frontier function methodology over the past several decades. This study employs a stochastic frontier approach introduced independently by Aigner et al. (1977) and Meeusen and van den Broeck (1977). The SPF approach (Figure 2) relies on a composed error structure where one component is normally distributed, and the other follows a one-sided distribution as depicted in equations (1) and (2):

$$y_i = f(x_i;\ \beta) + \varepsilon_i \qquad (1)$$
$$i = 1, \ldots, N$$

$$\varepsilon_i = v_i - u_i \qquad (2)$$

In this expansion, v_i represents a two-sided disturbance $(-\infty < v < \infty)$ assumed to be independent and normally distributed as $N(0, \sigma_v^2)$. The error term u_i is assumed to be one-sided, distributed independently of v_i, and to satisfy $u_i \geq 0$.[11] The disturbance term u_i is non-negative, indicating that each observation's output should lie on or below the frontier, thus capturing shortfalls in production. Alternative distributions (e.g., half-normal, exponential, truncated normal, and gamma) are possible, and make use of the maximum likelihood method of estimation (Greene, 1980). In the literature however, it has been pointed out that there may be little significant difference found between utilizing different distributions (Greene, 1990), and most studies follow a half-normal distribution (Bravo-Ureta & Pinheiro, 1993).

[11] In their, paper, Aigner et al. (1977) consider the relationship where $\varepsilon_i = v_i + u_i$ and $u_i \leq 0$. For the purposes of consistency with the greater literature, this relationship has been amended.

The TE for a given farm is calculated based on Jondrow et al. (1982). As such, technical efficiency, i.e. the ratio of the observed output (Y_i) to the corresponding frontier output (Y^*), conditional on the level of inputs used by that firm, can be expressed as follows:

$$TE_i = \frac{Y_i}{Y^*} \quad (3)$$

$$= \frac{f(x_i + \beta)\exp(v_i - u_i)}{f(x_i + \beta)\exp(v_i)}$$

$$= exp(-u_i)$$

3.1.4 Controlling for Selection Bias

When economists seek to determine the effects of treatment, they are trying to determine the difference between expected outcomes if an individual was treated compared to no treatment. In other words, the question is: "How would an individual have fared if they had not been exposed to the treatment?" This can be tricky to answer because an individual observed while receiving a particular treatment cannot simultaneously be observed not receiving that treatment.

Illustration of this problem is presented in the following set of equations (4 – 6). Equation (4) illustrates efforts to determine the difference in expected outcomes using observed data of treated individuals (Y_i^T) and non-treated individuals (Y_i^C); with T and C representing Treatment and Non-Treatment, respectively. This is followed by Equation (5), which adds and subtracts an unobservable term representing expected outcome for the control group, given treatment. This results in Equation (6), where the first term, $E\left[Y_i^T - Y_i^C \middle| T\right]$, represents the desired treatment effect, and the second term, $E\left[Y_i^C \middle| T\right] - E\left[Y_i^C \middle| C\right]$, indicates potential for problematic *selection bias* (Duflo, Glennerster, & Kremer, 2007).

$$E[Y_i^T|T] - E[Y_i^C|C] \tag{4}$$

$$E[Y_i^T|T] - \boldsymbol{E}[\boldsymbol{Y_i^C}|\boldsymbol{T}] - E[Y_i^C|C] + \boldsymbol{E}[\boldsymbol{Y_i^C}|\boldsymbol{T}] \tag{5}$$

$$E[Y_i^T - Y_i^C|T] + E[Y_i^C|T] - E[Y_i^C|C] \tag{6}$$

Selection bias, as introduced by Heckman (1979), is an issue of missing data as a result of unobservable factors or outcomes. Issues relating to selection bias arise from the possibility that those treated differ in some economically meaningful way from those that were not treated. How these groups are different may not be apparent or measureable. If the difference in the second term of Equation (9) is either greater or less than zero, is indicative of selection bias where those not treated given treatment have a different expected outcome than those not-treated in the absence of treatment.

In the case of farmers, though many living within similar geographic or socio-political communities will have comparable biotic and abiotic stressors, market opportunities, and access to information and extension; individual farmers will differ between crop choice as well as their household objectives and managerial capacities. Going further, Douglas (1980) identifies several factors, many unobservable, as characteristics of farmers that will likely influence their willingness to adopt. These factors include: knowledge of production practices, understanding of new technologies, acceptance and perceived credibility of new information sources, perception of the effort involved in adopting new technologies, as well as their level of control over adoption.

It would be much more effective to compare outcomes between those that indicated interest in and received treatment, and those that indicated interest but arbitrarily did not receive treatment, with the assumption that these two groups of people are similar in ways that are typically affected by selection bias. This is the logic behind increasingly popular randomized control trials (RCT) which assess impact by coordinating with program implementers to randomly assign treatment to

eligible and interested individuals. Despite the statistical benefits of using an RCT framework, there are a number of associated challenges such as long study duration periods, monetary costs, estimation of 'abstract' impacts, and ethical dilemmas with intentionally denying program benefits to typically needy individuals (Barrett & Carter, 2010).

Given the logistical challenges of employing 'gold standard' techniques such as RCTs and other experimental methods, the importance of quasi-experimental techniques take on greater relevance. Compared to experimental methods that have the benefit of clearly outlined selection criteria, quasi-experimental techniques allow for more flexible research agendas, provided that appropriate data is available. Indeed, there is a growing literature questioning whether practical concerns of RCTs contribute to any greater understanding than quasi-experimental methods (Deaton, 2010).

One of the more popular methods for controlling selection bias is propensity score matching (PSM). Attributed to the work of Rosenbaum and Rubin (1983), PSM serves to identify groups of individuals in both the treatment and non-treatment groups with similar specified observable characteristics. PSM often uses a regression probit or logit model where the dependent variable is binary indicating treatment and the explanatory variables are determinants of participation and outcome, independent of treatment effects. Using the estimated coefficients, a *propensity score*, or conditional probability of treatment, is calculated for each observation, which is then used to match between the treated and non-treated individuals on the basis of similarity in their propensity scores.[12] Based on this matching, some individuals in the treatment and non-treatment groups may be dropped, in order to create groups that are as similar as possible in terms

[12] For more information on the specific steps of PSM, see White (2006). For more information on constructing the specification selection model, see Caliendo and Kopeinig (2008).

of observable attributes. PSM offers the flexibility of specifying a number of alternative matching criteria.

Despite the popularity of the technique, it is important to remember that PSM is a method of controlling for observables contingent upon specification and data availability. A 1996 study by Heckman et al. attempted to quantify any remaining bias in a program evaluation following PSM by first randomly assigning treatment among members of an eligible pool of applicants to the largest federal job training program in the United States, and then continued to follow eligible applicants that declined to participate in the program for unknown reasons. By offering the same survey instrument to all three groups of individuals, those treated, those not treated, and those who opted not to be treated, Heckman et al. (1996) were able to compare the program's impact estimated through both experimental and quasi-experimental methods.

Results indicated that some selection bias was eliminated following PSM, but the bias that remained represented a substantial portion of the estimated impact. Though the authors did not speculate as to the causes of the remaining bias, it can be inferred that PSM's efficacy can only be as good as the observable variables available or chosen by the researcher as being indicative of willingness to participate in a treatment. Unfortunately, there are few tests available to determine to what degree their PSM 'works'; thus, it is critical to capture possible bias coming from unobservable variables.

Approaches to mitigate sample selection within SPF models include Kumbhakar et al. (2009) who assumed correlation between the selection mechanism and the error term u_i. A more recent contribution is a method proposed by Greene (2010) that assumes that unobserved characteristics in the selection equation (i.e. the logit or probit model) are correlated with the disturbance term v_i in the stochastic production frontier model.

3.2 Data and Sample Characteristics

The call for high quality data, particularly in the context of the SSA region, following concerns that governments are not maintaining appropriately updated or representative data records has led to the World Bank's Living Standards Measurement Survey – Integrated Surveys on Agriculture (LSMS) (Jerven, 2013). Indeed, the United Nations has called for a 'data revolution' to promote the capacities of the 'data-poor' and to close the gap between the unequal abilities of developed and developing countries to use data to address domestic development concerns (Independent Expert Advisory Group, 2014). LSMS, a donor-funded project initiated in 1980 by the World Bank to better understand general welfare and assist governments in improving living conditions through both household and community surveys (Grosh & Glewwe, 1998), was most famously utilized by Angus Deaton in his study of consumption patterns and welfare in developing countries (Deaton, 1997). With its current infrastructure in place, long-term financial support, and commitment to best-practice data collection procedures, LSMS is in a prime position to meet the growing demand for generating high quality data at reasonable cost.

With regard to economic studies interested in productivity and welfare analysis, LSMS additionally provides unique value given its easy accessibility, national sampling, and independence from agricultural institutions. The LSMS data, alternatively referred to as the Uganda National Panel Survey (UNPS), is an important source of information but one that still could be strengthened. Though centrally spearheaded by the World Bank, each LSMS country collects data under the auspices of their individual national statistics offices. Many of the survey practices are similar (national level, randomly sampled, rich household data) and can be used for the purpose of cross-country comparison, but variations in metrics and data availability do exist. Of particular interest to this study are gaps in obtaining information on specific intra-crop varieties,

managerial practices, consistent metrics required to measure yield, and general completeness of data.

The data utilized for this study is a 2011–2012 cross-section from the latest year available in an ongoing panel for Uganda (with a baseline in 2005–2006 and then continuously from 2009–2010 onwards). The full panel is unavailable owing to missing data with respect to adoption of improved seeds in previous years. As improvements are observed each year, both concerning data completeness and the expansion of questions, it is expected that future studies will be able to contribute increasingly valuable analysis regarding welfare outcomes.

Units of analysis are available at the household or farm level, and then by parcels, and more specifically by plots. For the purposes of illustration, a household can have one or more parcels, each of which in turn are divided into one or more plots. It is assumed that parcel and plot divisions are made by the household, not the enumerators, and can therefore be uneven. In order to account for unobserved intra-field variability, this study performs its analysis at the plot level. The dataset reveals that of the 496 plots, 87 are the second, third, or fourth plot growing groundnuts by a single household. This represents 38 farmers, three of which are IGV adopters. Given that the number of households that are posed with the decision of whether to be partial or full adopters is such a limited proportion of the dataset, this study defines the adoption rate as the absolute ratio of adopting plots to total plots without any weighting for household. Using this metric, the adoption rate is calculated to be 9.67 percent, with 48 out of 496 plots adopting IGVs.

Total Farm Area is calculated by summing up the total area of all plots belonging to a single household. It is measured in hectares (ha) and is calculated to be 1.19 ha on average, with Adopters averaging 1.45 ha and Non-Adopters averaging 1.16 ha. Owing to the fact that groundnuts are frequently grown for intercropping purposes, Plot Size (i.e. the area upon which groundnuts are

grown) is calculated by multiplying the portion of the plot upon which the household cultivates groundnuts, as indicated by survey data, by the plot area. Average Plot Size is 0.21 ha with Adopters averaging 0.30 and Non-Adopters averaging 0.2 ha. Recognizing that farmers will frequently grow several crops, the portion of Total Farm Area devoted to groundnut cultivation was calculated for each farmer and found to be 23 percent on average (as shown in Figure 3). Farmers with multiple groundnut plots were found to have 40.6 percent of their Total Farm Area devoted to groundnut cultivation, compared to famers with one plot, who grew groundnuts on 21.6 percent of their Total Farm Area.

As summarized in Table 3, 42 percent of household plots are in the Eastern region, 35 percent are in the West and Central regions, and 23 percent are in the Northern region. Amongst Adopters, 75 percent are in the East, 21 percent are in the North, and 4 percent are in the Central region.[13] Approximately 33 percent of households in the sample are female-headed households, a proportion that maintained itself when considering only Adopters, of which 33 percent were female-headed households. On average, there are 8-9 persons in a household, though, unsurprisingly, some households have up to 26 members.

The data additionally indicates that only 33 percent of households had contact with NAADS, though it is unknown whether the person in the household primarily responsible for groundnut cultivation was the individual who interacted with extension agents, or if the topic of extension was related to groundnut cultivation. It is additionally unknown which districts opted for groundnuts as one of their prioritized enterprises. As such, contact with NAADS can best be interpreted as general interest by a household in enhancing their productivity or commercializing their agricultural enterprises.

[13] For the purposes of regional dummy variables, the West and Central regions are considered to be one continuous region.

Average Yield is found to be 955.39 kg/ha, with Adopters on average yielding 1075.72 kg/ha, and Non-Adopters yielding 942.49 kg/ha. Yield minimums were found to be 3.29 kg/ha overall, and 30.89 kg/ha for Adopters. Given the effects of either or both diseases such as GRV and inefficiency on Yield, it is unsurprising to find such low Yield measurements. Yield was capped at 3,700 kg/ha during the cleaning of this dataset for Adopters and 2,500 kg/ha for Non-Adopters using yield data from NARO as a ceiling for both traditional varieties and IGVs.

3.3 Empirical Model

This study's empirical model is derived from Bravo-Ureta et al. (2012) where PSM is used to control for biases arising from observed characteristics in the calculation of ATT and SPF is used for the calculation of TE. The steps are as follows: (1) to model the determinants of adoption, (2) to match farmers using PSM in order to estimate ATT, (3) to estimate the SPF for all farmers, Adopters, and Non-Adopters. This empirical methodology does not make use of Greene's sample selection corrector owing to the small sample size of Adopters. The limitation of Adopter sample size also makes PSM unfeasible to trim the sample for estimating the SPF, especially in light of the lack of specific data on exposure. As such, results for TE stand on the strength of their variation across regions and groundnut cultivation environments, but have not otherwise controlled for observable or unobservable bias.

For Step 1, adoption is modeled as shown in Equation 7, with a binary variable equal to 1 for adopters, and z is a vector of exogenous variables explaining the decision of farmers to adopt IGVs, β are unknown parameters and w is the disturbance term distributed as $N(0, \sigma^2)$ (Villano et al., 2015).

$$Adopt = \beta_o + \sum_{j=1} \beta_j z_{ji} + w_i \qquad (7)$$

Here, region is employed as a proxy for exposure in tandem with environmental and political factors that are subject to multicollinearity if disentangled. For example, it can be hypothesized that farmers in areas with high GRV density may have a greater likelihood of adopting IGVs given the greater costs of the disease on production compared to other communities. Additionally, it is within expectations that farmers who are within proximity of the NARO breeding station or demonstration plots will be increasingly primed to adopt IGVs, given their relative access to awareness of new technologies. While these are all valid hypotheses, it is likely that controlling for such factors may ultimately overlap. GRV tends to appear in regions with high groundnut suitability, and that NARO activities typically take place where GRV's presence is strongest. Additional issues are present when it comes to the presence of groundnut commercial activity within a community, and the likelihood that NAADS will select groundnuts as one of their prioritized agricultural enterprises.

In the absence of specific data within LSMS such as availability of marketed IGV seed within a community, the selection of groundnuts as a NAADS enterprise, or the exposure of households to IGVs, indicators of environments conducive to adoption are compelled to become broader. Given the conjecture that much of the diffusion of IGVs is a result of NARO and NGO activity, it would have been preferred to employ spatial data on their activities, but unfortunately, this is unavailable. As such, this study turns to region, which has the benefit of encompassing both the spheres of activity for NARO (East) and NGOS (mostly North but also East), in addition to environmental factors such as temperature and precipitation, which have been shown to cluster within regions.

Additional determinants are described in Table 4, and include Household Number, Total Farm Area, Distance to Road, Elevation, Erosion, and Soil Quality. Inclusion of these variables follows expectation of either interest in increased production, access to information, or perception of beneficial outcomes. Given that Temperature interferes with Region, Elevation serves as a proxy for Temperature, with higher elevations experiencing colder temperatures. Additionally, Erosion acts as a control for environmental shocks, given that many in Uganda experienced landslides as a result of El Niño in 2010-2011. The data does not indicate that there is an inverse relationship between Erosion and Soil Quality, as might have been anticipated, leading to the assumption that households provide general information on Soil Quality, without taking into account the temporal circumstance of Erosion.

In Step 2, propensity scores are calculated by matching Adopting and Non-Adopting plots using the same variables as the adoption model in Step 1. The inclusion of specific covariates is considered on the basis of economic theory, previous literature, and information regarding the institutional setting as per Smith and Todd (2005) and Sianesi (2004). Following general practice, they are fixed over time and represent information not influenced by adoption. Not all variables in the adoption model are significant, following Rubin and Thomas (1996) to avoid trimming of relevant variables, especially given the highly unstable nature of IGV adoption in Uganda. Bryson, Dorsett, and Purdon (2002) advocate against over-parameterized models, which is kept in mind by limiting the model to five indicators, one exposure proxy, two regional dummies, and the shock term Erosion.

Matching criteria follows nearest-neighbor given its wide acceptance in the literature and its intuitive interpretation (Bravo-Ureta, Almeida, Solís, & Inestroza, 2011; Bravo-Ureta et al., 2012; Dillon, 2011; Rodriguez, Rejesus, & Aragon, 2007). No caliper is utilized in an effort to

maximize the inclusion of Adopters. Given the limits on data size and availability, PSM will be used solely in the capacity of estimating ATT.

For Step 3, this study employs a Cobb-Douglas functional form for both its intuition and popularity in farm efficiency models for the estimation of the SPF. The SPF model follows a Cobb-Douglas functional form for both its intuition and use in farm efficiency models. The specific model estimated follows Equation 8, where A and β are unknown parameters, ε is the composed error term as specified in Equation 2, and Y and $x_i$are variables as defined in Table 4.

$$lnY = lnA + \sum_{i=1} lnB_i lnx_i + \epsilon \qquad (8)$$

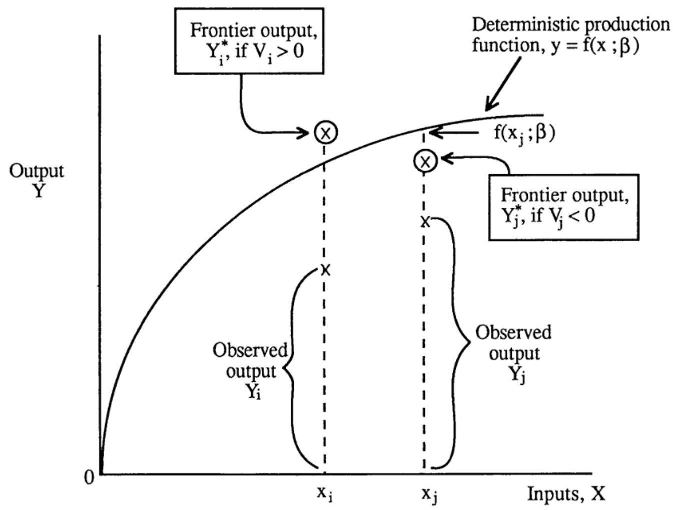
The model incorporates land, labor, and seed (both quantity and variety) as traditional variables, but also includes relevant determinants of TE including environmental factors such as Soil Quality and Precipitation, social factors such as Distance to Road and Gender, as well as exposure to knowledge regarding production practices as indicated by contact with NAADS. Given that it is a Cobb-Douglas functional form, all variables with the exception of dummy variables are logged, as indicated in Table 4.

The model employs a half-normal distribution, as is typical of most productivity studies (Bravo-Ureta and Pinheiro, 1993). During separation of SPF estimates, the IGV dummy is dropped for both the Adopter frontier and Non-Adopter frontier. Relevant statistical commands in STATA13 include *psmatch2* and *sfcross*, which allows for the calculation of TE.

3.4 Summary

This study employs a multi-stage framework to (1) to model the determinants of adoption, (2) to match farmers using PSM in order to estimate ATT, (3) to estimate the SPF for all farmers, Adopters, and Non-Adopters. Utilizing an SPF framework provides the benefit of allowing this study to disentangle technical inefficiency from statistical noise. Data comes from a 2011/2012 cross-section World Bank's LSMS country-wide survey, which has the benefit of offering comparisons between different regions, produced an adoption rate of approximately 10 percent as representative of the entire country. Plot level analysis allows for a sample size of 496, 48 of which have adopted IGVs. As a result of this limited sample size, efforts to control for biases from both observables and unobservables are unfeasible. Results should be understood to contain selectivity bias.

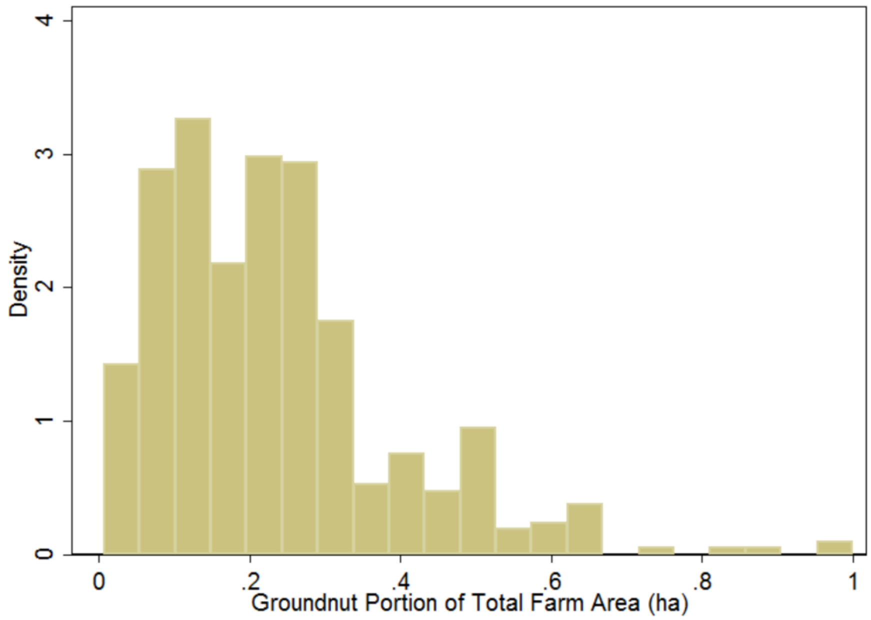
FIGURE 2: Stochastic Production Frontier of Two Firms



In this illustration of an SPF, Battese demonstrates how one firm (i) could find itself above the frontier, even if its output was less than that of another firm (j), indicated as positioned below the frontier. In this case, the firm above frontier might have a statistical noise value, represented as $\boldsymbol{v_i}$ *greater than 0. To be below the frontier, the other firm would have a statistical noise value,* $\boldsymbol{v_j}$*, of less than 0.*

Source: (Battese, 1992)

FIGURE 3: Proportion Of Total Farm Area Under Groundnut Cultivation



Min	.007	Max	1
Total Mean	.231 (n = 447 farmers)	Total Median	.180
Mean (# Groundnut Plots = 1)	.216 (n = 409 farmers)	Mean (# Groundnut Plots > 1)	.406 (n = 38 farmers)

TABLE 3: Summary Statistics

	Pooled Groundnut Farmers				*IGV Adopters*				*Non-Adopters*			
	Mean	Std. Dev.	Min	Max	Mean	Std. Dev.	Min	Max	Mean	Std. Dev.	Min	Max
IGV Use	0.10	0.30	0.00	1.00	1.00	0.00	1.00	1.00	0.00	0.00	0.00	0.00
Production (kg)	178.39	179.29	2.00	1400.00	285.08	229.71	15.00	1000.00	166.95	169.40	2.00	1400.00
Yield (kg/ha)	955.39	627.43	3.29	3294.74	1075.72	753.47	30.89	3294.74	942.49	611.98	3.29	2471.05
Total Farm Area (ha)	1.19	0.92	0.10	7.28	1.45	0.91	0.40	3.54	1.16	0.92	0.10	7.28
Plot Size (ha)	0.21	0.19	0.01	2.43	0.30	0.20	0.05	0.97	0.20	0.19	0.01	2.43
Distance To Road	7.04	6.57	0.00	31.79	6.84	6.37	0.04	21.35	7.07	6.60	0.00	31.79
Distance To Market	33.49	17.88	0.00	82.20	35.41	18.05	5.50	82.20	33.28	17.87	0.00	78.35
Hired Labor (Days)	5.49	13.07	0.00	120.00	8.29	14.75	0.00	65.00	5.19	12.85	0.00	120.00
Seed Quantity (kgs)	16.19	32.89	0.50	600.00	23.56	25.45	1.00	120.00	15.40	33.52	0.50	600.00
NAADS	0.33	0.47	0.00	1.00	0.50	0.51	0.00	1.00	0.31	0.46	0.00	1.00
Annual Temp. (C)	22.51	1.48	17.00	26.20	23.46	0.81	20.70	25.70	22.41	1.50	17.00	26.20
Elevation (m)	1179.64	181.85	629.00	2097.00	1108.81	105.39	797.00	1530.00	1187.27	186.72	629.00	2097.00
Annual Precip (mm)	1217.27	165.36	687.00	1615.00	1250.35	145.17	746.00	1440.00	1213.70	167.14	687.00	1615.00
Soil Quality	0.51	0.50	0.00	1.00	0.73	0.45	0.00	1.00	0.49	0.50	0.00	1.00
Erosion	0.63	0.48	0.00	1.00	0.60	0.49	0.00	1.00	0.63	0.48	0.00	1.00
East	0.42	0.49	0.00	1.00	0.75	0.44	0.00	1.00	0.38	0.49	0.00	1.00
North	0.23	0.42	0.00	1.00	0.21	0.41	0.00	1.00	0.23	0.42	0.00	1.00
Gender (Female)	0.32	0.47	0.00	1.00	0.33	0.48	0.00	1.00	0.31	0.46	0.00	1.00
N	**496**				**48**				**448**			

TABLE 4: Description of Variables in PSM and SPF Model

PSM-Logit Observables	Notation	Description
East	*z1*	1 if household currently resides in Eastern Region
North	*z2*	1 if household currently resides in Northern Region
Household Number	*z3*	Number of individuals in the household
Total Farm Area	*z4*	Total Farm Area in hectares encompassing all parcels and plots
NAADS	*z5*	1 if contact is made with NAADS extension
Distance To Road	*z6*	Distance of household from nearest major road in kilometers
Elevation	*z7*	Elevation of household in meters
Erosion	*z8*	1 if household experienced erosion
Soil Quality	*z9*	1 if soil quality was indicated as 'good'
SPF Production Inputs		
Production	*Y*	Groundnut production in kilograms. Converted from unconventional units.
Plot Size	*x1*	Plot size in hectares not including other household parcels or plots
Hired Labor	*x2*	Number of days of hired labor per hired worker.
Seed Quantity	*x3*	Amount of seed used in kilograms. Converted from unconventional units.
IGV Use	*x4*	1 if household adopts any quantity of IGV
Soil Quality	*x5*	1 if soil quality was indicated as 'good'
Precipitation	*x6*	Annual precipitation in millimeters
Distance To Road	*x7*	Distance of household from nearest major road in kilometers
Gender	*x8*	1 if household is headed by a woman
NAADS	*x9*	1 if contact is made with NAADS extension

CHAPTER FOUR: RESULTS

This Chapter presents the results for the model introduced in Chapter Three. The results for the Adoption Logit are provided in Table 5 and the maximum likelihood estimates for the stochastic production frontier using the half normal distribution are presented in Table 7. IGV use has a coefficient of .133 and approaches significance under the half normal model, but is significant at the 10 percent level with a coefficient of .176 for both the truncated normal and exponential distribution models. ATT is calculated to be 293.89 kg/ha post-matching. The results provide evidence that steps should be taken to promote the managerial capacity of groundnut farmers. Alternatively, it seems clear that a larger number of observations is required in order to obtain robust estimates for the coefficients of the Adopter SPF model. Thus, greater emphasis will be paid in the discussion below to the results from the Pooled model containing all groundnut farmers.

4.1 Determinants of Adoption

Logit estimates for the determinants of adoption (Table 5) indicate that there is a strong and statistically significant regional bias towards the Eastern region (.20) and the Northern region (.124) for likelihood of adoption compared to the Western & Central regions. Contact with NAADS plays a small but significant role at the ten percent level (.048). Abiotic shocks such as Erosion demonstrate a significant negative impact on likelihood of adoption (-0.064) while general perceptions of plot fertility, as demonstrated by Soil Quality, have a highly significant impact on adoption (.107).

Of interest is the result that Total Farm Area does not have a significant impact on adoption and indeed is correlated with a slightly negative impact (-0.001). This goes against expectations

given the assumption that larger farms are more likely to be commercialized and therefore will have greater access or incentive to access information. The fact that Total Farm Area is not positively correlated with Adoption is potentially indicative of the poor market institutions surrounding IGV diffusion and access. Future studies will need to confirm whether the result of non-impact is biased from a lack of exposure.

Other indicators such as Household Number, Elevation, and Distance to Road conform to expectations in their correlations but are largely negligible. Distance to Road is indicative of access to social networks and was expected to have a stronger negative impact. The interpretation is that as Distance to Road increases, so does relative isolation from markets where farmers could either obtain information or market their agricultural output. The fact that Distance to Road does not have a stronger negative impact on adoption is noteworthy given the assumption that if IGVs were reliably available in local markets and trading centers, Distance to Road would serve as an effective proxy to access.

Typical determinants of adoption under reliable market and extension conditions (Total Farm Area, Distance to Road, and NAADS) are not as critical as would be expected, and give reason to further speculate that IGV dissemination is being done through informal pathways. This is further compounded by the fact that regional indicators such as the Eastern region, where NARO has a heavy presence, and the Northern region, where NARO also has a presence in tandem with the proliferation of NGOs, have such as strong impact on adoption. Though groundnuts are not a largely exported crop when compared to other national commodities such as coffee, markets do exist in Kenya, which some Eastern farmers have access to, and South Sudan, which Northern farmers have more access to. The relevance of both Erosion and Soil Quality indicate that farmers in contact with diffusers of seed are making rational decisions as to their perceived utility of

adoption versus to not adopting, compared to a scenario where they are temporarily utilizing IGVs because they may have been free or heavily subsidized.

As explained earlier, contact with NAADS will likely indicate self-selection in trying to promote the commercial potential of agricultural enterprises, but may not specifically have been a result of an interest in improving groundnut productivity. As such, it is critical to specifically account for exposure in order to obtain and disentangle estimates for determinants regarding access and perceived utility.

4.2 Controlling for Observables Using PSM

Evidence from PSM indicates that prior to matching, the mean bias across determinants was 32.9 percent, which was reduced to 10.9 percent after matching, i.e. a 66.87 percent reduction in bias. Indicators exhibiting significant levels of mean difference between Adopters and Non-Adopters included the Eastern region, Household Number, Total Farm Area, NAADS, Elevation, and Soil Quality. Unmatched average means were statistically different at the 1 percent level. After PSM, a match for all Adopter plots was found (48 pairs), and the entire sample size fell within the common support (Figure 4). Post-matching (Table 6), all covariates balanced, indicating no significant difference between the Adopter and Non-Adopter groups. Following matching, Average Treatment on Treated (ATT) was determined to be significantly different (t-stat = 1.94) and estimated a difference of 293.89 kg/ha compared to the unmatched ATT of 133.32.

4.3 SPF Estimates

Results for the Cobb-Douglas SPF can be interpreted as partial elasticities, and are presented in Table 7. Pooled land and labor results are significant at the 1 percent level for Plot Size, but are not-significant and indeed have a very marginal magnitude coefficient for the use of

Hired Labor. These results are consistent with expectations regarding smallholder agricultural systems, which are understood to operate on extensive margins and have limited labor efficiency. With the rural labor force swelling as the population rises, it can be anticipated that Hired Labor will be of limited productive value. Seed Quantity is also significant at the 1 percent level.

The sum of these partial elasticities (land, labor, and seed quantity) is less than 1 for all three models (Pooled, Adopter, and Non-Adopter), indicating decreasing returns to scale following the proportional increase of inputs, and is therefore consistent with expectations following other studies on smallholder farmers. Other variables included in the SPF are also consistent within expectations, with Precipitation being significant at the 5 percent level, indicating its relative importance to rain-fed agricultural systems. Soil Quality is additionally significant at the 5 percent level, upholding assumptions that increased fertility and appropriate soil type are more conducive for production.

The estimation that the Distance to Road has a significant negative direction is also consistent, potentially indicating that as a household is further removed from major transportation routes, increased isolation from markets is likely to decrease access to information and diminish commercial motivations of farmers. Female heads of households are found to have a positive correlation with production. This is plausible given the cultural understanding of groundnuts as being a ‘women’s crop’, in tandem with the suggestion from Tanellari et al. that when women are married, that they may be pressured into providing labor for their spouse’s plots, in addition to other household activities.

The role of NAADS is the most curious element of the production frontier, with results indicating an inverse relationship between contact and production. It is possible that farmers who interact with NAADS are inherently low-performers, either because they are the ones most

desperate for assistance, even with the reputation of NAADS, or potentially because they might individuals who are largely interested in the free lunch that is provided. Alternatively, it is possible that farmers interacting with NAADS are not specifically consulting the extension agency regarding groundnut cultivation, and as a result, the negative association with production is an indication of decreased interest or specialization in groundnut cultivation.

With the understanding that IGVs and other improved varieties are intended to promote productivity along intensive margins as opposed to extensive margins, it is worth considering how production frontiers may differ when use of IGVs is separated from use of traditional seed varieties. This exercise however, is made difficult by the use of the LSMS dataset, given that the limited sample size of IGV adopters can lend itself to noisy results and non-converging estimates. As such, only the disentangled estimates for the half normal distribution are presented.

Interesting results in Table 7 include the difference in partial elasticities for Plot Size, with Adopters' estimates being approximately half of that for Non-Adopters of IGVs. Other unusual estimate differences are that for Soil Quality, as well as the relevance of Precipitation and the extension service NAADS. Interpretation for the limited effects of Plot Size and Soil Quality on productivity for Adopters could be as a result of the enhanced robustness of IGVs against biotic and abiotic factors, indicating that increasing land size has less of an impact on production, with similar logic being applied to the relationship of Soil Quality and IGV productivity. This is contrary to results for Non-Adopters, who are likely to experience strong impacts from both increasing Plot Size and enhanced Soil Quality.

The inverse relationship between Precipitation and IGV production is within expectations, given that groundnuts, especially IGVs, have been known to fail under high precipitation conditions on research plots, given the enhanced nature of their drought-resistant and therefore

arid-loving attributes. Additionally, it is well within expectations that Adopters are more likely to benefit from interaction with NAADS, given that their technologically progressive attitudes make them more likely to be receptive of training, possibly with regard to general management practices. That Seed Quantity is not only not-significant, but has a decreased magnitude coefficient is additionally within expectations as well as a positive result, that production levels are less dependent on the quantity of seeds used, therefore saving on input costs.

An extreme Lambda value is observed for the Adopter SPF model, and can be understood to be the division of Sigma U by a Sigma V value that approaches 0. This reinforces expectations that the separated frontier estimates for Adopters have too low a sample size to be relied upon.

4.4 SPF Across Distributions

Estimates of impact from the use of IGVs differed across distributions (half normal, truncated normal, and gamma), with the half normal model indicating no significant difference in production between adopters and non-adopters, whereas the truncated normal and exponential models estimated significant impacts at the 10 percent level for IGV use with a coefficient of .176 for both models (Table 10). The half normal distribution estimated a coefficient of .133 for IGV use. Estimates of technical efficiency varied across distributions with the half normal model indicating an average TE estimate of .457, while the truncated normal and exponential distributions yielded estimates of .547 and .548 respectively.

Log-Ratio tests were employed to detect differentiation across distributions. The results, as presented in Appendix A: Table 11, indicate a significant difference between the half normal and truncated normal distributions, and similarities between the truncated normal and exponential distributions. Due to the infeasibility of extending the truncated normal and exponential distributions to other elements of analysis, the half normal distribution was selected for primary

presentation. Given that that under the half normal distribution that IGV use is not significant, this study finds their use to have ambiguous but positive impact.

4.5 Technical Efficiency Estimates and Output Predictions

Average technical efficiency for groundnut farmers in Uganda is low, with estimates across distributions ranging from .457 (half normal) to ~.548 (truncated normal and exponential). Individual estimates range from .005 to .925 (half normal) and .006 to .910 (truncated normal and exponential). Though there are many farmers with higher rates of TE, there is also a sizeable clustering with extremely low rates, indicating that managerial capacity is an issue that requires urgent address.

Efforts to determine trends in TE across region and various agro-market indicators are presented in Appendix A: Figure 5 and Table 8 respectively. As seen in Figure 5, TE maintains its skew and mean estimates across regions. Additional comparison, as presented in Table 8 demonstrates that there is a relative similarity between farmers with high and low TE across factors ranging from their purchase of seed (given that saved seed is more likely to harbor vulnerability to pests and disease) to awareness of and participation in extension programs, as well as generally low access to land ownership titles, which may have had an impact on whether farmers were inclined to invest in land either through inputs or labor.

When SPF is separated into two frontiers for IGV Adopters and Non-Adopters, average TE (HN) is observed as being .518 and .463 respectively. The fact that Adopters have a higher average TE can be plausibly interpreted as residual selectivity bias from Adopters being inherently more interested in production practices and therefore more efficient. These farmers may already be likely to have adopted integrated pest management practices such as placing a buffer around

their fields to avoid attracting pests from surrounding tall grass, or applying equal spacing while planting seeds.

Alternatively however, the mean TE for Adopters under the separated SPF model is still quite low, and when the distribution of TE is examined, it demonstrates a similar, but more prominent, bimodal shape. This is potentially due to the dissemination of IGVs by NGOs who may have specifically identified farmers because they were likely to be low-performing or required assistance in developing a new agricultural enterprise. In comparison, Non-Adopter TE is more evenly distributed, but large elements of the sample still have very low TE.

Efforts to determine which factors are relevant to low TE is inherently undermined by the absence of data on indicators such as agronomic practices, seed variety, whether utilized seed has been purchased or is home-saved, or the incidence of common shocks such as GRV or drought. Agronomic practices will fundamentally affect efficiency given that they complement IGVs by warding off pests. In one study by NARO, pest management practices such as early sowing were found to have a similar impact as IGVs on minimizing GRV, but only 42 percent of farmers were utilizing them (Mugisa et al., 2015). It is hypothesized based on the magnitude of the TE gaps that the absence of management practices is playing a role, but this will need to be quantitatively tested.

Other factors such as seed varieties, both IGV and traditional, will have attributes that either increase their yield under ideal conditions or make them more robust to poor conditions and therefore may not have similar potential. Home-saved seed, as explained earlier, can be more susceptible to pests and diseases, and those very shocks, can have the ability to wipe out an entire plot, thus leading to low TE. Whether a not a household plot is operating in a GRV hotspot is a critical environmental factor that should be taken into account for calculating TE. The LSMS

dataset is very rich on socio-demographic indicators, but without these basic insights, there will be little understanding about how to improve TE for farmers that cannot afford or access IGVs.

The results for predictions on Output (kgs), Yield (kg/ha) and Output Value (UGX and USD) are Table 9. Predicted Output is calculated using observed data and stored estimates from the SPF for each of the models. Predicted Yield is calculated by dividing Predicted Output by observed Plot Size. Output Value is determined by multiplying Predicted Output by average LSMS price data (2,682 UGX) and then converting that price into USD using the 2011 exchange rate of 2,500 UGX/USD. Results indicate that Predicted Output is high compared to Observed Output, indicating the large gap in TE by observed farmers. Predicted Yield is considered high compared to similar productivity studies, but is consistent with and appropriately lower than NARO estimates. Estimates of Predicted Output Value indicate a return of $324 per kg for all farmers.

4.6 Field Impressions & Policy Implications

Low rates of adoption as indicated by the LSMS data are consistent with impressions from field work. Informal interviews with relevant stakeholders ranging from NARO plant breeders, to NAADS agents, NGOs, seed company officials, and input dealers provide a few key insights. First, is that the relationship between NARO and NAADS as an institution is weak, and as a result, exposure to IGVs on the part of information diffusion agents is limited to those with whom NARO scientists have personal relationships. This is relevant to other sources of diffusion such as NGOs and seed companies. Formal pathways for sharing information regarding the development of new agri-inputs appears to be lacking and, as a result, relationships at the personal level of NARO officers is more relevant than an institutional relationship. The second point is that IGV availability from agro input dealers is limited, with dealers in Kampala just as unaware of IGVs as a small

seed trader in the Northern highway town of Kamdini (an established stop on the road between Juba and Nairobi) who cannot distinguish between different types of groundnut seed.

A third point relates to both adoption and TE estimates given that many farmers who grow groundnuts, are likely to grow several crops in addition to other income generating enterprises and therefore may not be likely to have a sufficient interest in obtaining information regarding productive groundnut practices, much less implementing them. In Kamdini, it was explained that farmers do not have a market outlet for their groundnuts, and post-harvesting practices are minimal. Many farmers are known to sell groundnuts without even removing the dirt and also struggle with transporting them. The head of the NARO breeding program has indeed expressed frustration that smallholders are not adopting seeds and also do not implement appropriate pest management practices. Input dealers in the large Northern cities of Gulu and Arua offer similar opinions in that IGVs, when purchased, are primarily bought by farm groups and commercial farmers.

In a domestic seed sector described by regulatory officials as having low certified input use and high concerns of adulteration, it is plausible that without commercial opportunities placing a focus on groundnuts, farmers who grow them will not be inclined to adopt IGVs given their cost and general risk aversion. With the overhaul of NAADS and the introduction of Operation Wealth Creation, it is suggested that IGV stakeholders lobby for the inclusion of IGVs as a prioritized input. This would provide a secure market for seed companies and also provide heavily subsidized inputs to farmers. Alternatively, funding should be made available to NARO to increase their demonstration sites and facilitate transportation to areas both within and beyond the Northern and Eastern regions.

Without greater outreach directly to smallholder farmers, it is highly unlikely that objectives of food security will be realized. If practices continue, it's possible that IGVs are adopted primarily by large commercial farmers thereby furthering inequalities in the production systems. In the absence of farmer interest to adopt seeds that may either be costly or have different taste and aesthetic attributes, emphasis should be placed on promoting pest management practices.

4.7 Summary

Analysis on the productivity effects of IGV use indicates that there are benefits to adopting IGVs, but greater potential benefits to closing gaps in managerial capacity. Literature from NARO indicates that several management practices may have similar effects on the degree of GRV severity (Mugisa et al., 2015). Compounded by the fact that over 40 percent of farmers are not currently using any management practices, and that the likelihood of adoption is limited, real opportunities exist for improving productivity by targeting management practices.

Of interest in this discussion is identifying which farmers should be targeted by stakeholders. Informal field interviews with seed traders have indicated both the paucity of seed availability, but also that the primary consumers are commercial farmers and farmer cooperatives. Commercial farmers are less likely to be concerned with taste attributes, and more likely to be interested in seeking out productivity enhancing inputs. The distinction here is between farmers that are commercial groundnut farmers and those that happen to grow groundnuts either for intercropping or family consumption.

In the analysis we were not able to make use of methods to correct for unobservable selectivity bias, but made efforts to control for relevant observable biases by including regions as a factor in PSM for the calculation of ATT. The use of region is intended to account for exposure

and sensitization as well as environmental attributes, but future research explicitly specifying these factors is warranted.

FIGURE 4: PSM Logit Matches

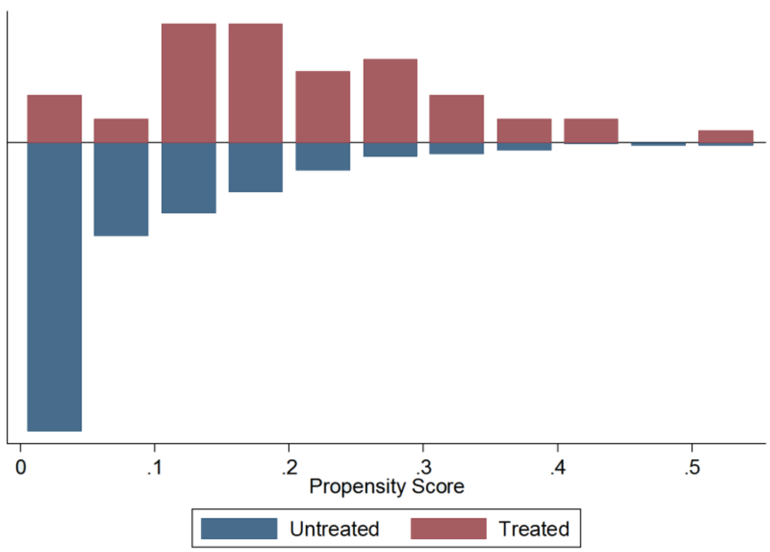


TABLE 5: Adoption Logit Estimates				
	Coefficient	*Std Error*	*Margins*	*Std Error*
Constant	-3.282	2.164	--	--
East	2.605***	0.791	0.200***	0.062
North	1.612*	0.855	0.124*	0.067
Household Number	0.049	0.041	0.004	0.003
Total Farm Area	-0.009	0.198	-0.001	0.015
NAADS	0.622*	0.349	0.048*	0.027
Distance To Road	-0.029	0.025	-0.002	0.002
Elevation	-0.002	0.002	0.001	0.000
Erosion	-0.829**	0.388	-0.064**	0.030
Soil Quality	1.398***	0.399	0.107***	0.030

TABLE 6: Balance Test Of Means					
	Treated	*Control*	*% Bias*	*t-stat*	*p>|t|*
East	0.750	0.792	-9	-0.48	0.632
North	0.208	0.167	10	0.52	0.606
Household Number	9.958	9.500	9.7	0.45	0.653
Total Farm Area	1.453	1.782	-36	-1.45	0.150
NAADS	0.500	0.458	8.6	0.40	0.687
Distance To Road	6.840	7.187	-5.4	-0.25	0.806
Elevation	1108.80	1111.50	-1.8	-0.12	0.904
Erosion	0.604	0.646	-8.5	-0.42	0.677
Soil Quality	0.729	0.771	-8.8	-0.47	0.642

Table 7: SPF Estimates (HN)

	Pooled		*Adopters*		*Non-Adopters*	
	Coefficient	Std Error	Coefficient	Std Error	Coefficient	Std Error
Constant	3.175**	1.356	10.904		3.166**	1.460
Plot Size	0.677***	0.051	0.337***	0.013	0.678***	0.054
Hired Labor	0.005	0.004	0.009	0.007	0.007	0.004
Seed Quantity	0.180***	0.035	0.162	0.126	0.193***	0.038
IGV Use	0.133	0.09				
Soil Quality	0.118**	0.058	-0.107	0.188	0.153**	0.062
Precipitation	0.483**	0.192	-0.613***	0.029	0.477**	0.206
Dist. To Road	-0.052**	0.021	-0.045	0.065	-0.061***	0.023
Gender	0.094	0.062	-0.575***	0.193	0.132**	0.066
NAADS	-0.050	0.06	0.147	0.164	-0.078	0.064
Sigma_U	1.288***	0.057	1.327***	0.135	1.251***	0.060
Sigma_V	0.235***	0.037	0.000	0.000	0.254***	0.039
Lambda	5.486***	0.082	747180.2***	0.135	4.927***	0.087
Average Te	**0.46**		**0.52**		**0.46**	

TABLE 8: Comparing High And Low TE Across Agro-Indicators (TN)		
	TE > .55	*TE < .55*
Purchased (Any) Seed	39.64	42.13
Output Purchased By Private Traders (Local Market)	61.18	51.16
Output Purchased By Consumer (Local Market)	17.11	25.58
Output Purchased By Private Traders (District Market)	18.42	16.28
Awareness Of NAADS	83.93	80.56
Participation In NAADS	18.21	17.59
Documentation Of Land Ownership	16.82	17.58
Gender	30	33.8

TABLE 9: Observed and Predicted Production

	Pooled	***Adopters***	***Non-Adopters***
Predicted Output Mean (kg)	302.405	514.662	278.281
Predicted Output Max	3172.526	1154.273	3092.634
Predicted Output Min	25.420	193.902	24.454
Predicted Yield Mean (kg/ha)	1593.561	2003.540	1544.763
Predicted Yield Max	3299.793	4297.338	3412.402
Predicted Yield Min	432.895	936.323	413.999
Av. Output Value (UGX)	811050.48	1380323.48	746350.18
Av. Output Value (USD)	324.42	552.13	298.54

CHAPTER FIVE: SUMMARY AND CONCLUSIONS

This thesis intended to examine the potential of IGVs to improve yields and production while measuring the managerial capacity of adopting farmers compared to peer farmers that utilize traditional varieties in Uganda. A contribution of this study is the employment of nationally representative data as an effort to mitigate biases from regional differences, a factor that has not been fully considered in the literature. Results reveal that the adoption rates for IGVs is 10 percent, which is significantly lower than previous estimates of over 50 percent. However, these results are consistent with the fact that the other available studies have been performed in sites that are close to the NARO research station and this is likely driving the higher regional adoption rates. Estimates of TE indicate that there is theoretically room to double production without the adoption of IGVs, and that TE remains low even when only Adopters are considered. The impacts of adoption are inconclusive given low sample size. The half normal distribution is employed and does not yield a significant impact from adoption, but other distributions offer significant results.

If organizations such as USAID intend to prioritize the promotion of IGVs for the purposes of food security over the their potential as marketable commodities, then it is recommended that they redirect their efforts away from prolific plant breeding, and towards programming that will promote diffusion of technologies and the fostering of effective management practices. Breeders do acknowledge that even without IGVs, high yields can be obtained from traditional varieties if proper planting practices are observed. As such, it is of interest to consider the promotion of pest management practices.

In order to promote the use of IGVs, it needs to be acknowledged that typical pathways of diffusion are not effective in promoting exposure or access. Indeed, given that the Government of Uganda has recently dismantled NAADS in favor of Operation Wealth Creation, which will serve

primarily as an input distribution platform, there is a good opportunity for vested stakeholders to consider how to leverage shifting policies to promote IGV adoption. Results from this study support focusing on the Eastern and Northern regions of Uganda, where there is an existing interest in groundnut production.

As the institutional environment becomes increasingly dynamic, it is recommended that the analysis reported in this study be extended. To this end, there is scope for improvement, both through the utilization of panel data, but also through the incorporation of additional information that will help to minimize selectivity bias. Current efforts in the literature to control for bias may be computationally taxing on small datasets and therefore additional relevant information is required. Such data includes seed varieties, use of crop management practices, exposure to relevant inputs, and information regarding the type of production systems that farmers have (i.e. subsistence, smallholder, cooperative, or commercial). Without such data, it will be difficult for researchers to make specific recommendations that might be useful to policy makers.

As it stands, it is highly possible that the adoption of IGVs may take place among larger commercial farmers thus increasing inequities in the process of rural development. However, even if gaps in adoption are addressed, general TE still needs to be enhanced if the technology is to be truly effective and suitable for improving food security in an environment of growing challenges posed by climate change.

APPENDIX A: ADDITIONAL RESULTS

TABLE 10: Pooled SPF Estimates Across Distributions

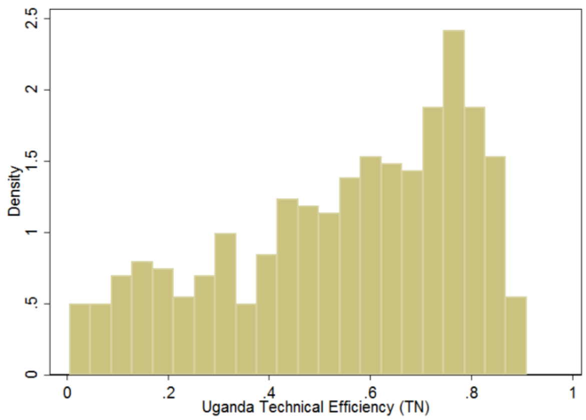
	Half Normal		*Truncated Normal*		*Exponential*	
	Coefficient	Std Error	Coefficient	Std Error	Coefficient	Std Error
Constant	3.175**	1.356	2.775**	1.336	2.775**	1.336
Plot Size	0.677***	0.051	0.646***	0.045	0.646***	0.045
Hired Labor	0.005	0.004	0.006	0.004	0.006	0.004
Seed Quantity	0.180***	0.035	0.195***	0.032	0.195***	0.032
IGV Use	0.133	0.090	0.176*	0.092	0.176*	0.092
Soil Quality	0.118**	0.058	0.151***	0.056	0.151***	0.056
Precipitation	0.483**	0.192	0.493***	0.188	0.493***	0.188
Dist. To Road	-0.052**	0.021	-0.059***	0.020	-0.059***	0.020
Gender	0.094	0.062	0.121**	0.060	0.121**	0.060
NAADS	-0.050	0.060	-0.060	0.058	-0.060	0.058
Sigma_U	1.288***	0.057	29.086	64.715	0.774***	0.052
Sigma_V	0.235***	0.037	0.333***	0.031	0.333***	0.031
Lambda	5.486***	0.082	87.322	64.715	2.324***	0.072
TE	**.457**		**.547**		**.548**	

TABLE 11: COMPARING DISTRIBUTIONS USING LR-TEST

NULL HYPOTHESIS	Calculated χ^2 Statistics	Degrees of Freedom	Decision, 0.90	Decision, 0.95
$\boldsymbol{H_0: HN - TN = 0}$	22.23	1	Reject H_0	Reject H_0
$\boldsymbol{H_0: HN - Ex = 0}$	--	0	--	--
$\boldsymbol{H_0: TN - Ex = 0}$	0.00	1	Accept H_0	Accept H_0

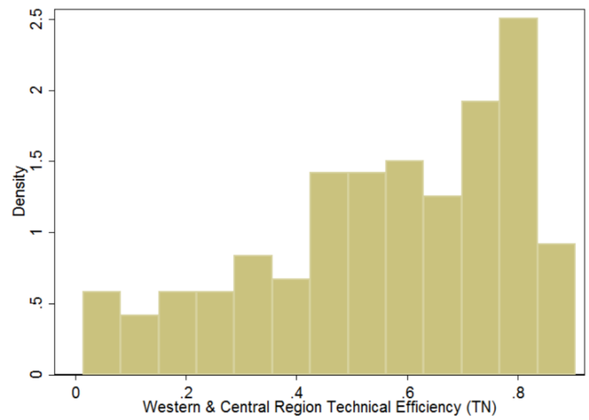
FIGURE 5: Technical Efficiency (HN) By Region

UGANDA



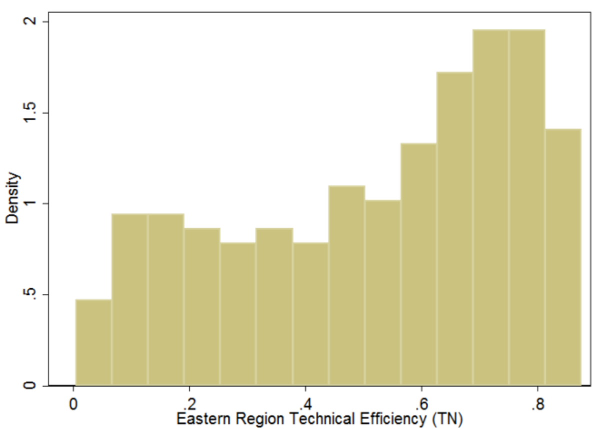
Mean = .547 n = 494

WEST & CENTRAL



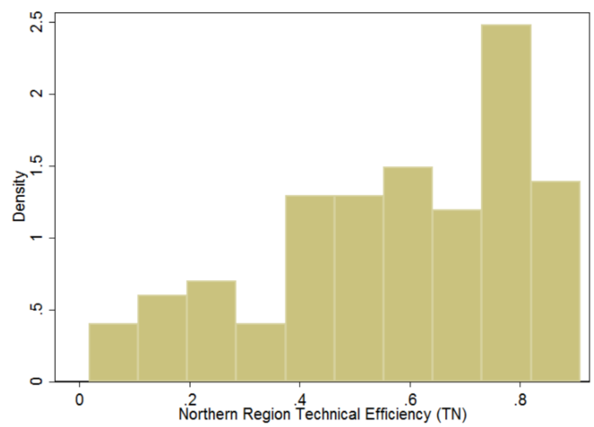
Mean = .562 n = 175

EAST



Mean = .521 n = 206

NORTH



Mean = .572 n = 113

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