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Estimating the Impact of Agricultural Technology on Poverty Reduction in Rural Nigeria

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Notices

[1] Effective January 2007, the Discussion Paper series within each division and the Director General's Office of IFPRI were merged into one IFPRI–wide Discussion Paper series. The new series begins with number 00689, reflecting the prior publication of 688 discussion papers within the dispersed series. The earlier series are available on IFPRI's website at www.ifpri.org/pubs/otherpubs.htm#dp.

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Contents

List of Tables

List of Figure

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ABSTRACT

It has often been argued that new agricultural technologies lead to poverty reduction. This paper argues that any changes in poverty situation attributed to those who adopt new agricultural technology (treatment group) without a counterfactual comparison of carefully selected nonadopters (control group) are likely to be questionable. The paper estimates the effects of new agricultural technology on poverty reduction by employing the "double difference" method on data collected in rural Nigeria. Seeing the agricultural technology–poverty linkage through the lenses of adopters and nonadopters of such new technology provides understanding of the relationship between agricultural technology and poverty. The paper finds that differences in poverty status between adopters and nonadopters of new agricultural technologies (a combination of tube wells and pumps) introduced in rural Nigeria in the late 1980s and early 1990s are alarmingly modest. The paper concludes that new agricultural technology would not expressly lead to poverty reduction in poor countries. The exact channels through which new agricultural technology impact poverty outcomes need to be further explored.

Keywords: Poverty, evaluation, inequality, impact assessment, agricultural technology, difference-in-difference methodology, Nigeria

1. INTRODUCTION

The attention given to the eight time-bound, quantifiable, and monitorable Millennium Development Goals (MDGs) by the leaders of 189 countries at the United Nations Millennium Summit in 2000 has moved poverty reduction to the very top of the international development agenda (Deaton 2003, 2004a, 2004b; United Nations Millennium Project 2005).[1] This is because out of the eight MDGs, poverty reduction is now the undisputed overriding goal of development and the primary challenge facing the developmental community today.

Yet despite dramatic global poverty reductions recorded in the last three decades, it has been projected that, under the most likely scenario, both absolute numbers of poor people and the share of people living on less than US$1 per day in sub-Saharan Africa will increase by 2015 in comparison with that of the reference year 1990 (World Bank 2003, 2004). While other developing regions of the world are making significant progress in achieving the first MDG, poverty rates in sub-Saharan Africa have been increasing.

Many reasons have been attributed to the rise in absolute numbers of poor people and the proportion of people living in extreme poverty in sub-Saharan Africa. These reasons range from inequality due to the trends of globalization, to violent civil conflict, governance failures, and institutional gaps. However, since the majority of people living on less than US$1 a day in sub-Saharan Africa live in rural areas where agriculture is their predominant source of livelihood, the prominent explanatory factor attributed to the rise in regional poverty rates is the reduction in absolute value of aid volumes and government expenditures to agriculture and rural infrastructure (Booth and Mosley 2003; Lipton 2000; IFAD 2001; World Bank and IFPRI 2006). Thus, for instance, the share of total World Bank lending to agriculture declined from about 31 percent in the late 1970s to below 10 percent in the early 2000 decade (World Bank 2006).

It is now generally believed that investment in agricultural technology must be prioritized in sub-Saharan Africa in order to achieve the core MDG of halving the proportion of people living in extreme poverty and hunger by 2015. This is because the massive investments in agricultural technology in some of the Asian economies in the 1960s and 1970s have been successful in feeding growing populations, achieving rapid economic growth, and boosting employment generation (Lipton and Longhurst 1989; Rosegrant and Svendsen 1993; Saleth 2002). Indeed, the past five decades have witnessed serious promotion of agricultural technology in many developing Asian countries with broad objectives of achieving food self-sufficiency, agricultural and rural development, and poverty and hunger reduction.

Although the translation of the effect of agricultural technology into poverty reduction in Asia has received huge attention in the literature, it remains underresearched in sub-Saharan Africa. Even those studies explicitly concerned with the measurement of poverty reduction impacts of agricultural technology have tended to focus primarily on the direct adopters of such technologies. Scholars, development practitioners, and policymakers have consistently overlooked the differential poverty reduction of new agricultural technology between adopters and nonadopters inhabiting the rural communities where such agricultural technologies are introduced. To make the decision that investments in agricultural technology in developing countries alleviate poverty, their poverty reduction impacts need to be evaluated within the context of the differences between their adopters and nonadopters.

Consequently, this paper seeks to contribute to the literature on the impact of agricultural technology on poverty reduction in Africa by analyzing the poverty reduction impacts of new agricultural technologies in the form of a combination of tube wells and pumps for plentiful agriculture in rural Nigeria. Following this introduction, Section 2 discusses issues relating to the connection between agricultural technology and poverty reduction and provides a step-by-step account of the methods and

[1] The eight Millennium Development Goals (MDGs) to be achieved by 2015 are halving extreme poverty and hunger; attaining universal primary education; promoting gender equality; reducing child mortality; improving maternal health; halting the spread of HIV/AIDS; ensuring environmental sustainability; and fostering a global partnership for development.

techniques utilized in the paper. Section 3 describes the data and the survey area. Section 4 estimates the effects of agricultural technology on poverty reduction, and Section 5 concludes.

2. AGRICULTURAL TECHNOLOGY–POVERTY LINKAGE

Two main challenges confront anyone seeking an understanding of agricultural technology–poverty linkages. One challenge, which is paradigmatic, regards how best to conceptualize agricultural technology–poverty linkages that would capture the multidimensionality of poverty. The other challenge is that of sifting through a welter of interpretations and interventions by researchers and analysts who have attempted to evaluate the impact of agricultural technology on poverty reduction.

For several decades, the diagnoses of the linkages between agricultural technology and poverty have often been indirect and arising from the impact of technical change in agriculture or agricultural productivity growth (see, for example, Pinstrup-Andersen and Hazell 1985; Ahluwalia 1978; Dhawan 1988; Freebairn 1995; Fan and Hazell 2000; Datt and Ravallion 1998). For instance, the predominant literature on the poverty linkage effects of agricultural growth during the 1970s tend to show that technical change in agriculture leads to more production, which in turn leads to increased incomes for households with land. The latter are believed to use most of the incomes they make from agricultural production in purchasing labor-intensive goods and services, thereby leading to second- and third-round effects of providing food security and more employment opportunities for the poor (Mellor 1976, 2001).

Many of the studies on the effects of agricultural technology on poverty tend to show that there are strong complementarities between physical infrastructure and human capital (see, for instance, Biswanger et al. 1993; Canning and Bennathan 2000; Datt and Ravallion 1997, 1998). It was not until recently that explicit mention of the relationship between agricultural technology and other complementarities began being featured in the literature. Thus, for instance, Shah et al. (2002) illustrate how small investments in agricultural technology can benefit landless households directly through production of vegetables and fruits and indirectly through employment generation. Evidence from some Asian countries also demonstrates how small-scale technologies self-target the poor to increase their income levels. The inadequacy of explicit agricultural technology–poverty linkages for several decades has not only complicated efforts to understand the relationship between agricultural technology and poverty reduction and to design ways to make agricultural technology more effective in lifting poor people out of poverty, but it has also made evidence on the agricultural technology–poverty linkages partial and indirect. Most studies indicate that agricultural technology may reduce poverty through direct effects on output levels, employment, food security, food prices, incomes, and overall socioeconomic welfare. The type of technology adopted tends to be responsible for the type of poverty-reducing impacts that can be expected from agricultural technology (Litchfield et al. 2002; Lipton et al. 2003; Hussain et al. 2002; Hussain and Hanjra 2003, 2004). The evolving concept of the broader relationship between agricultural technology and the poor necessitates direct estimation of effects of agricultural technology on poverty reduction.

Because of the assumption that agricultural technology automatically reduces poverty, antipoverty impacts have often been developed mostly for their adopters and focused exclusively on them. This approach fails to spell out an adequate counterfactual situation and obscures the significance of agricultural technology as a poverty-alleviation weapon without comparing adopters with nonadopters. The question that might then be explored is: How can an agricultural technology–poverty linkage be properly conceptualized within the context of both adopters and nonadopters? Put differently, can the conceptualization of agricultural technology–poverty linkage be structured in such a way as to allow comparability between adopters and nonadopters? The fundamental response that this paper demonstrates is that this question can be answered in the affirmative, especially when looking at the issue of the agricultural technology–poverty linkage in a particular setting. The counterfactual analysis is based on a fundamental characteristic that some people adopt a particular agricultural technology while others do not in a particular setting, village, or geographical area.

Several methods of evaluating a counterfactual analysis of antipoverty development programs abound in the evaluation literature (see Ravallion 2005). The two most popular standard methods used for evaluating antipoverty development programs or social experiments are the *single difference* methods, which compare outcomes between a sample of adopters and one of nonadopters, and the *double difference* or *difference-in-difference* methods, which compare outcome indicators with-and-without before and after adoption by using a preintervention baseline survey and postintervention data.

However, three problems are associated with the two standard methods. According to Ravallion (2005), the first problem is selection bias, which is related to how one can deduce the counterfactual for adopters with regard to nonadopters who have different characteristics. To resolve this problem, it is important to ensure comparability between adopters and nonadopters in terms of their preintervention characteristics. Failure to ensure the latter would imply that the observed differences in outcome indicators between adopters and nonadopters cannot be taken as valid. Thus, for instance, Glewwe et al. (2004) show that selection biases resulted in higher test scores of school children in Kenya, and van de Walle (2002) reports that selection biases for the evaluation of the impact of rural roads on poverty attributed larger income gains to project beneficiaries when in fact there are no income gains.

The second problem is related to spillover effects of antipoverty development programs in which efforts must be made to understand the important spillover benefits of new agricultural technology to its nonadopters. When spillover effects are ignored, it is very likely that the evaluation results might be underestimated and biased (Heckman et al. 1999; van de Walle and Cratty 2005). The third problem is concerned with data and measurement. If the data sources collected and the survey instruments used for the data collection are not comparable or consistent between adopters and nonadopters, then outcomes of such impact analysis are likely to be biased. Ravallion (2005) reports that Heckman et al. (1999) illustrate how differences in data sources between project participants and nonparticipants can seriously undermine evaluation results using the United States training programs.

Although the use of single difference methods is prevalent in the evaluation literature, these methods generally tend to furnish impact analysis with inadequate information on whether the control group is similar to the treatment group in terms of all characteristics with the exception of adoption of new technology. Scholars like Miguel and Kremer (2004) who have tried to use the single difference method have in some ways encountered complications using it in their evaluation of treatments for intestinal worms in children. They then mention that the omission of externalities between children who received treatments and those who did not tend to lower the measured impacts of the intervention.

Arguably one of the most important achievements of the evaluation literature is the introduction of the double difference or difference-in-difference methods, in which adopters and nonadopters of development interventions are compared in terms of changes in desired outcome indicators over time, usually before and after the interventions. The double difference methods are superior to the single difference methods because they help to resolve the selection bias in single difference comparisons through the matching of two comparable groups—those who adopt new technology and those who do not. Nevertheless, it is important to emphasize that using a difference-in-difference approach does not eliminate all unobserved heterogeneity of individuals who may adopt new technology and those who do not, nor the selection bias that may affect a program's decision on whom to allocate the intervention within a particular village.

To estimate the effects of agricultural technology on poverty, that is, to quantify the character of the relationship between agricultural technology and poverty, it is important to establish both the unconditional treatment effect (i.e., without holding other factors constant) and the conditional treatment effect (i.e., taking all other factors into consideration). It is also crucial to make a strong assumption that the adopters and nonadopters of specific agricultural technology have no other differences apart from the fact that the former adopt new agricultural technology while the latter do not. Regression analysis will help to determine if adoption of a new agricultural technology is a statistically significant determinant of the changes in the poverty levels of the respondents studied.

To estimate the treatment effect of agricultural technology on poverty, the paper follows the most popular standard method in the published literature called the double difference or difference-in-difference method by comparing changes in desired outcome indicators between a treatment group (adopters) and a comparison group or control group (nonadopters) over time before and after the introduction of new technology (see, for instance, Pitt and Khandker 1998; Cook 2001; Jacoby 2002; Chen and Ravallion 2003; Ravallion 2005; Ravallion and Chen 2005; Galiani et al. 2005).

In this paper, the two groups are indexed by treatment status, $T = 0$ or 1, where 0 indicates nonadopters (the control group) and 1 indicates adopters (the treatment group). Estimated data were collected on the observed individuals in two time periods—before and after the introduction of new agricultural technology—$t = 0$ or 1, where 0 indicates a time period before the treatment group adopted the new agricultural technology (pretreatment) and 1 indicates a time period after the treatment group adopted the new technology (posttreatment). Every observation is indexed by the letter i = 1,.....,N; individuals (each of the adopters and nonadopters) will typically have two observations each, one pretreatment and one posttreatment.

More formally, the full model to estimate the unconditional treatment effect of agricultural technology on poverty can be expressed as

$$Yi = \alpha + \beta Ti + \gamma ti + \delta(Ti * ti) + \varepsilon i \tag{1}$$

where the coefficients given by the Greek letters α, β, γ and δ are all unknown parameters and εi is a random, unobserved error term that contains all determinants of poverty, *Yi* omitted by the model. Note that the coefficients have the following interpretation:

α = constant term,

β = specific effect of the treatment group, which accounts for average permanent differences between the treatment and control groups,

γ = time trend common to both the treatment and control groups, and

δ = poverty effect of the new agricultural technology (treatment).

The difference-in-difference estimator is the estimate of δ, the coefficient on the interaction between *Ti* and *ti*. Please note that δ is the coefficient that measures the effect of the dummy variable, which takes the value 1 only for the treatment group in the postadoption (posttreatment) period. This is because *Ti* is a dummy variable taking the value 1 if the individual is in the treatment group and 0 if the individual is in the control group, while *ti* is also a dummy variable taking the value 1 in the posttreatment period and 0 in the pretreatment period. The purpose of the estimation is to find a "good" estimate of δ, given the available data. The sign of δ will indicate if the treatment group had a bigger or lesser change in observed outcome than the control group, while the size of δ will indicate what extra change in observed outcome the treatment group had. In the situation where the dependent variable, *Yi*, is a continuous variable like income, the difference-in-difference estimator will be the ordinary least squares (OLS) estimate of δ, and T-statistics will indicate if the coefficient δ is statistically significant different from 0 or not.

However, in the situation where the dependent variable such as poverty incidence is not a continuous variable like income because it takes the value of 0 or 1 depending on whether or not a household is poor, a logit model is estimated to determine the unconditional poverty effect of agricultural technology. The use of a logit model is justified quite simply. Logit models extend the principles of OLS to better treat the case of dichotomous and categorical variables such as poverty headcounts by allowing a mixture of categorical and continuous independent variables to predict one or more categorical dependent variables. Logit models focus on association of categorical data, looking at all levels of possible interaction effects. Logit models are based on traditional approaches to analyzing categorical data by relying on chi-square as a measure of significance to establish if a relationship exists in a table, and then come up with a number, usually between 0 and 1, indicating how strong the relationship is.

Because numerous factors condition whether agricultural technology will benefit the poor, and these factors interact in complex ways, and because poverty has many determinants, the paper takes an important step further in the agricultural technology–poverty linkage by identifying those factors and characteristics that somehow alleviate or elevate poverty and pinpointing the relative importance of each of those factors in affecting poverty status. This is because poverty is an outcome that is determined by categories of factors or explanatory variables such as landholdings, labor, harvests, markets, education, and other personal household characteristics.

Following the standard model presented in equation (1), the poverty headcount measures of both the treatment and control groups are then regressed on different types of relevant determinants of poverty by deriving a logit model for the poverty headcounts as presented in equation (2):

$$Yi = \alpha + \beta Ti + \gamma ti + \delta (Ti * ti) + \lambda isXis + \varepsilon i \qquad (2)$$

where *λis* represent the coefficients of the *Xis*, which are a set of the relevant determinants of poverty. This exercise lends itself to drawing conclusions regarding whether agricultural technology could lead to a significant reduction in poverty or not.

3. DATA AND SURVEY AREA

Basic Background Profile and Characteristics of the Survey Area

Defining and evaluating impact analysis with particular reference to the slippery concept of poverty, quantifying the choice of a welfare indicator for poverty analysis, discriminating between poor and nonpoor, and identifying appropriate data sources for analysis make researching poverty assessments of agricultural technology a challenging and inherently controversial subject. The complexities involved in impact analysis definitely mean that it is virtually impossible to accurately measure the impact of agricultural technology on poverty no matter how rigorous or robust the data used for such analysis. Therefore, the data utilized for the analysis in this paper should be interpreted as rather crude measures of the true values.

For the analysis in the paper, both adopters and nonadopters of the agricultural technologies were selected from the same geographical location, same geographical proximity, same production system, same weather conditions, and same altitude. They are all Muslims, share the same culture and beliefs, and are men. This is because the study focuses on the semiarid Sahelian region where farmers are smallholders utilizing simple agrarian technologies in a region notable for the vicissitudes of recurrent drought and highly unreliable rainfall. Prior to the introduction of the new agricultural technologies, both adopters and nonadopters combined rainfed and irrigated farming production as their primary means of livelihood. Both the selected adopters and nonadopters resemble one another in many relevant respects. The key critical difference between the two groups is that while one group adopted new agricultural technology, the other group did not.

The data collection procedure for the study involved three different fieldwork components. The first component was a preliminary visit of six weeks to the selected survey area in Jigawa state of northern Nigeria to get acquainted with the inhabitants of the several villages in the survey area. The preliminary visit led to the selection of a potential field site for the study. The second fieldwork component was the pilot study. The pilot study phase involved the conducting of interviews with the residents, community leaders, and well-informed local officials in the several villages in the selected survey area through informal village meetings and unstructured key informant interviews to clarify the characteristics of agricultural technologies in the region. During the pilot survey, it was also possible to field-test the questionnaires used during the third phase of the fieldwork as well as to gather rich information on the profiles of the selected five villages where in-depth fieldwork took place during the third phase of the study.

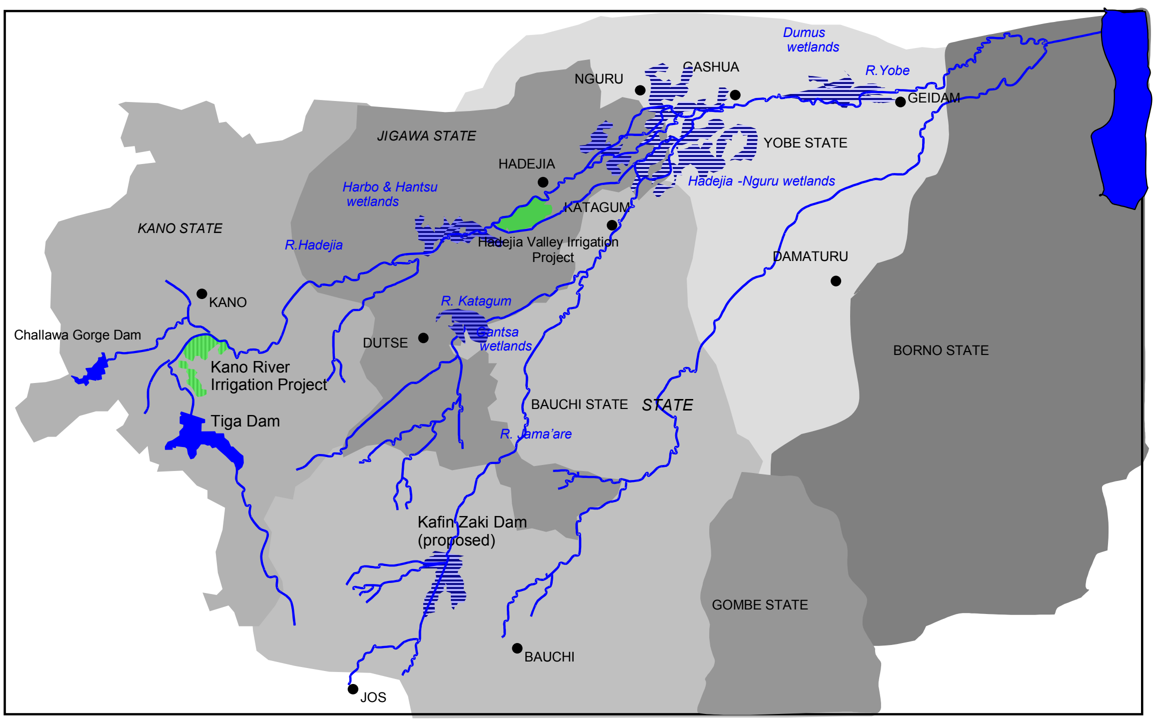
The third phase of the fieldwork component was the main fieldwork survey in which in-depth collection of data took place between 2004 and 2005. A total of 200 adopters and 200 nonadopters were selected for the study because of the multistage random sampling approach adopted, which tends to require larger samples than single-stage designs in order to achieve high degree of precision.

The first stratum for sampling involved the Agricultural Development Programs (ADPs) in the northern Nigerian states of Sokoto, Kebbi, Zamfara, Kano, Kaduna, and Jigawa. Within the dry savanna region in northern Nigeria comprising of these six states, Jigawa state was purposively chosen as the field site for the study, and this formed the second stratum. Two important reasons informed the choice of Jigawa state. First, Jigawa state, which was carved out of Kano state in August 1991, was one of the five northern Nigerian states that championed and pioneered the development of and investment in small-scale agricultural technologies in Nigeria. Second, during the preliminary visit to the survey area, it was realized that agricultural technologies are more concentrated within the Hadejia-Nguru floodplain wetlands in Jigawa state than in any other northern Nigerian states.

At the chosen research location of Jigawa state, the Jigawa Agricultural and Rural Development (JARDA) headquarters in Dutse provided official permission and letters of recommendation to conduct the study. For effective grassroots coverage of the various agricultural activities in Jigawa state, JARDA is divided into four operational zones with headquarters at Birni Kudu, Gumel, Hadejia, and Kazaure.[2] The Hadejia operational zone of JARDA was selected for the study from the four operational zones, and this formed the third stratum. The Hadejia operational zone was naturally selected because almost 98 percent of small-scale agricultural technologies via the extraction of groundwater using low-cost petrol-driven pumps in the whole of Jigawa state are situated in the Hadejia operational zone of JARDA.

The Hadejia emirate has eight local government areas (LGAs)—Auyo, Birniwa, Hadejia, Kaffin-Hausa, Mallam Madori, Kaugama, Kirikasama, and Guri—and Kirikasama LGA was selected for the field study, which represented the fourth stratum. Kirikasama LGA was specifically chosen because 80 percent of dry-season irrigation activities in the Hadejia zone are located in Kirikasama LGA. As a matter of fact, Kirikasama LGA is completely situated in *fadama* (irrigable land), which has led to a more intensive economic development of the area and resultant higher increased human population than in many other parts of Nigeria. Indeed, for anyone seeking to understand the impact of small-scale agricultural technologies on poverty reduction in Nigeria, there is probably no better place to begin than Kirikasama LGA within the Hadejia zone of Jigawa state because of the high prevalence of small-scale irrigation activities in the LGA.

Figure 1. The survey area



The fifth stratum of the sampling technique took place at the village level. By using a rapid rural assessment method, a quick tour of all the villages in Kirikasama LGA was made in order to obtain a

[2] Please note that there are six technical departments at the headquarters of JARDA. Each of the departments is headed by a director. All the zonal managers and the subprogram directors make up the Project Management Unit headed by the managing director. Like other similar agencies in other states, JARDA is charged with the task of implementing every facet of agricultural development and extension activities in Jigawa state. JARDA is actually the implementation arm of the Jigawa state's Ministry of Agriculture and Natural Resources (MANR). JARDA has the responsibility of constructing rural roads, storage and cooling facilities for crops, rehabilitation of buildings, and the management of tube well drilling and irrigation pump supply contracts in Jigawa state. The input supply arm of JARDA that distributes irrigation pumps for marketing purpose is called Jigawa State Agricultural Supply Company (JASCO).

general picture of the prevailing situation with regard to the use of agricultural technologies. Five different villages were selected for the study, and all five were from Kirikasama LGA. These villages, situated within the Hadejia-Nguru floodplain wetlands in Jigawa state of Nigeria, are Jiyan, Likori, Matarar Galadima, Turabu, and Madachi. The five villages were purposively selected through considerable effort to ensure that they were representative of other villages in the same general location. In any case, the other villages that could easily have been chosen within Kirikasama LGA were not accessible as a result of flood at the commencement of the fieldwork. The villages selected differ in their ease of access to the main city in the area (Hadejia) and in their relative access to transport networks and urban markets.

Selection of Adopters and Nonadopters for the Study

Indigenous irrigation has been a common and long-standing phenomenon in the study area. Dry season cultivation using both traditional irrigation and recession farming techniques has been a major feature of the communities within the study area—so much so that it has been a useful supplementary to the main rainfed agriculture and has actually informed the decision of many migrants to settle within the study area by forming nucleated villages to access land.

Table 1. Characteristics of the five survey villages

	Jiyan	Matarar Galadima	Turabu	Madachi	Likori
Location	Southeast of Hadejia, about 60km from Nguru	Southeast of Hadejia, about 52km from Nguru	Directly east of Hadejia, about 49km from Nguru	Eastern part of Hadejia, about 44km from Nguru	Eastern part of Hadejia about 37km from Nguru
Distance to the nearest paved road/main city of Hadejia	About 8–9km to Hadejia road	17km to Hadejia road without crossing the Hadejia river, but normally 19km if crossing Hadejia river	20km to Hadejia road	25km to Hadejia road	32 km to Hadejia road
Cultivable irrigable land and upland	100 square meters	50 square meters	30–40 square meters	Less than 20 square meters for cultivation; no single farm in southern and eastern part; like a small peninsula because of flood	40 square meters
Estimated population[3]	6,000 people	4,000 people	8,000 people	7,000 people	8,000 people
Ethnic composition[4]	80%–90% Hausa; 10%–20% Fulani	90% Hausa; 10% Fulani	90% Hausa; 10% Fulani	80–85% Hausa; 15–20% Fulani	80% Kanuri; 10% Hausa; 10% Fulani
Average annual rainfall (2003–2005)	576.3mm	584.5mm	591.4mm	620.7mm	565.1mm

The potential for dry season irrigation in the study area is hinged on the availability of substantial surface and groundwater resources, particularly along the northern rivers. These surface and groundwater

[3] Based on interview with the local leaders of the villages
[4] Based on interview with the local leaders of the villages

resources are usually harnessed to develop small-scale private irrigation. On the one hand, perennial streams, ponds, lakes, and rivers constitute the main sources of surface water for irrigation purpose through the use of different technology devices to lift surface water in the study area. On the other hand, the main sources of groundwater for irrigation purpose in the study area are shallow tube wells by drilling, popularly referred to as *tube wells*, and shallow tube wells by washboring, popularly called *washbores*.

Until the early 1980s, irrigation in the study area was undeveloped and constrained by available technology (the traditional water-lifting devices, such as the labor-intensive *shadouf,* calabash, and rope and bucket irrigation from channels, which are used to lift water onto the land).[5] Water lifting by such devices can only irrigate a land area limited to about 0.1 hectare per *shadouf* through a very laborious process. These devices are low cost and dependent mostly on farmers' labor for construction and operations. They also have low discharge and flow rates that are definitely not adequate for irrigating large areas of irrigable farmland. These irrigation techniques are tedious and very time-consuming.

In the study area where the villages are situated, several technical experts have been promoting the use of low-cost simple agricultural technologies for exploiting shallow groundwater based on the successful agricultural technologies used in the South Asian region. Since the late 1980s, JARDA has been promoting tube wells with motorized pumps to farmers. These motorized pumps are either powered by fossil oils or driven by electricity. Many of the motorized pumps can irrigate at least one hectare of farmland and have considerable water delivery capacity relative to traditional irrigation technology devices. The agricultural technologies, which became very popular because they could be owned and operated by an average farmer, marked the advent of modern agricultural technology in the study area, and by extension in the whole of Nigeria. While some farmers willingly adopted the newly introduced agricultural technologies, others were reluctant to adopt such technologies.

Many Fadama Users Associations (FUAs) have been formed in the study area, including the selected five villages, to access both tube well and motorized pump irrigation packages that were randomly allocated by JARDA. FUAs were actually formed based on voluntary, free, and independent association among interested farmers. FUAs have well-defined aims and roles serving a common purpose of farmers. They also receive support from JARDA through loan packages for irrigation pumps and tube wells, trainings on pump operation and maintenance, water management, record keeping, rural mechanics, and marketing among others. Those who can read and write serve as secretary, treasurer, or chairman and manage the administrative running of their members.

Each FUA had approximately 25 farmers. Some of the FUAs in the study area engage in the joint purchase of drilling/washboring services, mutual transport and marketing of inputs and outputs, and operation and maintenance of motorized pumps. Usually, there are different units of FUAs with different sets of executives running the administrative affairs of their units. While there were nine different units of the FUAs in Turabu village, Madachi, Likori, and Matarar Galadima villages had four different units of FUAs, each with three different units of FUAs in Jiyan village.

The subexecutives of the FUAs have compiled lists of members of their associations, which are updated as new members join the associations and were used as a basis for the study. Only men are registered members of FUAs in the five villages, and therefore all the names included in the lists are of men.[6] All members of the FUAs in the five villages have adopted the new tube well and pump technologies. Of the adopters for this study, 40 farmers were selected from each of the survey villages directly from the different units of the FUAs in the villages. Thus, 40 adopters were selected from 229 members of FUAs in Turabu; 40 adopters were selected from 96 members of FUAs in Madachi; 40 adopters were selected from 96 members of FUAs in Likori; 40 adopters were selected from 100

[5] *Shadouf* is a long slender pole, which has a container usually made from animal skin attached to its rear end.

[6] This is in line with the religious and cultural beliefs in northern Nigeria, which tend to comparatively prevent women from engaging in farming activities and gaining access to and control over productive resources. Many of the women in northern Nigeria tend to engage in some income-generating activities such as agricultural processing, which take place within the home so as to comply with *purdah*. It thus happens that the poorer the household, the more likely the women are involved in income-earning activities that can be carried out within the home, and vice-versa.

members of FUAs in Matarar Galadima; and 40 adopters were selected from 80 members of FUAs in Jiyan. Accompanied by the leaders of the FUAs, we walked through the five villages matching names of adopters as identified by the leaders of the FUAs with their respective households.

For the selection of nonadopters, 40 nonadopters of new tube well and pump technologies were selected from each of the survey villages who are not registered members of FUAs. The names of the nonadopters in the five survey villages were also compiled. The lists compiled contained 114, 94, 121, 73, and 88 names in Jiyan, Likori, Madachi, Matarar Galadima, and Turabu, respectively. Systematic random sampling was used to select an approximately equal number of observations of the treatment group and the control group. This was done by assigning identification numbers to the names of the adopters and the nonadopters. For each of the villages, these identification numbers were written down on individual slips of paper and thrown into two separate hats: one hat for the names of adopters and the other hat for the names of nonadopters. These hats were vigorously shaken, and then 40 slips of paper were picked out from each of the hats.

Data Collection

Data were collected on the general socioeconomic characteristics of respondents, which include age, gender, marital status, household size, educational level, major occupation, secondary occupations, farming experience, number of land assets owned and cultivated, residency type, and membership of association. Information was also collected on their farm and nonfarm income levels and sources of income. Table 2 presents a basic summary on age and household composition of respondents. The overall average age of all the adopters sampled is very similar to the overall age of all the nonadopters sampled. Although the latter was not a function of survey design, it reflects the point highlighted earlier that both the selected adopters and nonadopters resemble one another in all respects, including age. It also shows that the respondents interviewed are still very active and old enough to have accumulated enough experience before and after technology adoption.

Although the respondents interviewed are not exactly alike in terms of their household composition, some generalization of the structure of household composition of the respondents was generally observed. The respondents and their corresponding household members tend to live in groupings related to farming practices and family links. As with many rural people in the study area of northern Nigeria, the respondents were observed living in two distinct broad groupings, namely *gandu* (plural: gandaye) and *iyali* in local Hausa language. Several authorities have written extensively on the *gandu* and *iyali* groupings (see, for instance, Norman 1972; Norman et al. 1982; Udry 1991). Basically, "*gandu* organization implies that there are two or more adult men, one or more of them married, jointly operating a common set of fields. The production process is generally supervised by one of them; as in a father-son *gandu*, for example, where the father is the chief decision maker" (Norman et al. 1982: 64). It is also possible to have brother-brother *gandu* organizations in which married brothers dwell together with the members of their households in the same compound.

Iyali organization, on the other hand, "implies that the grouping includes only one adult man and his dependents. In some cases, an *iyali* group closely resembles a nuclear family, but polygamous families also qualify. Nephews, nieces, grandchildren, and grandparents are often members of *iyali* groupings" (Norman et al. 1982:65). In the selected survey villages, it was realized that each compound of the respondents may contain one or more households organized as either *gandu* or *iyali* groupings. But compounds in the survey villages are physical rather than social or socioeconomic: There are physical partitions within each compound to reflect a division into multiple households. Although the occurrence of *gandu* household composition is waning in the study area, it is slightly difficult to ascertain the number of people per household.

Table 2. Age and household composition of respondents

Basic Characteristics	Adopters	Nonadopters	z-statistics[7]
Number of Observations	200	200	-
Average Age	48.5	48.1	0.15
Number of Respondents of Ages 21–30	2	2	-
Number of Respondents of Ages 31–40	30	38	-
Number of Respondents of Ages 41–50	98	86	-
Number of Respondents of Ages 51–60	48	56	-
Number of Respondents of above Age 60	22	18	-
Household Size	12.5	11.6	1.70*
Number of Respondents of Household Size, 1–10	83	100	-
Number of Respondents of Household Size 11 and Above	117	100	-
Average Number of Adult Males in the Household	2.0	1.9	1.03
Average Number of Adult Females in the Household	2.5	2.3	2.55**
Average Number of Children in the Household	8.0	7.4	1.03

Source: author's fieldwork
**significant at 5%, *significant at 10%

The total number of people in the households of the selected adopters and nonadopters is similar for the respective survey villages. Many of the households of the respondents in three of the five survey villages (Jiyan, Likori, and Turabu) have 11 or more people. While 60 percent, 87.5 percent, and 82.5 percent of the households of the *adopters* sampled in Jiyan, Likori, and Turabu villages, respectively, have 11 or more people, the corresponding figures for the *nonadopters* are 50 percent, 57.5 percent, and 67.5 percent. The household sizes in the survey villages are large. This is probably because the inhabitants of the survey villages and the surrounding villages are rather gatherers of people. Many of the respondents are of the opinion that large household sizes are better than small household sizes. They integrate a lot of extended family members into their households, partly for readily available labor for agricultural production activities and partly because of the influence of cultural and ethnic factors that encourage them to dwell together. Nevertheless, the household sizes of the respondents for this study follow similar patterns of household sizes of the rural dwellers in the corner of Nigeria where the research was undertaken.

The high prevalence of numbers of household members in the study area is closely associated with the prevalence of *gandu* household organization, in which married sons remain within the paternal households, or even the *iyali* household organization, in which nephews or sons who are big enough to work on the farm but not old enough to marry remain in the households. Thus, for instance, Hill (1972:32–37), in her classical study on rural Hausa, reports that 32 percent of households in Batagarawa village in Katsina state had 11 or more people. In his own seminal study titled, *Silent Violence: Food, Famine and Peasantry in Northern Nigeria*, Watts (1983: 398) records that 23.2 percent of households in Kaita village in Katsina state had 11 or more members.

Educational Level of the Respondents

Differentials in the educational levels of respondents interviewed in the five survey villages are large. Analysis of Table 3 statistics show that Quranic form of education is prevalent, in which many of the respondents had their highest formal training. The prevalence of Quranic form of education is relatively higher among the nonadopters than the adopters in all the five survey villages.

[7] Please note that z-test is a test of statistical significance for bivariate analysis. The hypothesis tested with z-test is typically based on continuous data that assume normal distribution. Although z-test and t-test are equivalent tests with the same inference, I have used z-test in this study because t-test is used when sample sizes are small (i.e., sample sizes < 30), and z-test is used with larger samples, as in the case of this study (i.e., sample sizes > 30).

Table 3. Level of education of adopters and nonadopters

Level of Education	Adopters	Nonadopters	Total
None	69 (34.5%)	65 (32.5%)	134 (33.5%)
Primary	33 (16.5%)	35 (17.5%)	68 (17.0%)
Secondary	7 (3.5%)	4 (2.0%)	11 (2.8%)
Postsecondary	4 (2.0%)	3 (1.5%)	7 (1.8%)
Quranic school	87 (43.5%)	93 (46.5%)	180 (45.0%)
Total	200 (100.0%)	200 (100.0%)	400 (100.0%)

Source: author's fieldwork
Note: Chi-square ($\square^2$) = 1.339 and P value = 0.855, not significant at $p < 0.05$

It is crucial to test the means of all relevant household, farm, and individual characteristics to determine if they are equivalent between the treatment and control groups prior to technology adoption. To determine whether there is a relationship between the proportion of the adopters and nonadopters interviewed according to their levels of education, the null hypothesis (H0) and alternative hypothesis (H1) are set up as follows:

H0: There are no differences between the adopters and nonadopters in the frequencies of their levels of education.

H1: There are differences between the adopters and nonadopters in the frequencies of their levels of education.

Based on the chi-square value presented in Table 3, the null hypothesis is accepted that there are no significant differences between the adopters and nonadopters in the frequencies of their levels of education. This implies that the levels of education between the treatment and control groups are equivalent prior to technology adoption.[8]

[8] Please note that chi-square (χ^2) is a nonparametric test of statistical significance for bivariate tabular analysis. The hypothesis tested with chi-square is typically based on whether or not two different samples are different enough in some characteristics. I have used chi-square test here because it is the appropriate test to determine whether the number of individuals in different categories fit a null hypothesis (an expectation of some sort) when dealing with counts or enumeration data that are discontinuous. Chi-square is more likely to establish significance to the extent that (1) there is a strong relationship, (2) there is a large sample size, and (3) two associated variables have a large number of values. I have used a chi-square probability of 0.05 (i.e., $p = 0.05$) since a chi-square probability of 0.05 or less is commonly interpreted by social scientists as justification for rejecting or accepting the null hypothesis about the relationship between two samples.

4. RESULTS AND ANALYSIS

Disaggregation of Assets of Treatment and Control Groups

This section further disaggregates access to different assets by treatment and control groups, including land assets with the prime objective of setting a stage for discussions and analyses. The section examines the nature, magnitude, and distribution of assets of the two groups in terms of two categories. The first category deals with land assets (plots of *fadama*, or irrigable land, owned and cultivated; and plots of upland, or rainfed land, owned and cultivated), land tenure, and land location. This is important because land is a fundamental factor of production in the study area that is closely associated with the farmer's choice of agricultural technology. The second category is focused on access to market.

Land Assets of Treatment and Control Groups

In the specific context of the survey villages for this study, two types of land tenure dominate. The first is land received as an inheritance (locally called *gado*), which is usually held by the owning family for life and is usually passed down from one generation to another within the owning family. Of course, the subdivision of family landholdings through inheritance (*gado*) usually leads to increased fragmentation of farmlands. *Gado* is by far the most significant land tenure system found among the respondents sampled (Table 4).

Table 4. Tenure of farmland of the adopters and nonadopters

Tenure of Farmland	Before Adoption			After Adoption		
	Adopters	Nonadopters	Total	Adopters	Nonadopters	Total
Inheritance all	148 (74.0%)	144 (72.0%)	292 (73.0%)	112 (56.0%)	139 (69.5%)	251 (62.8%)
Rent or Purchase all	4 (2.0%)	1 (0.5%)	5 (1.3%)	6 (3.0%)	3 (1.5%)	9 (2.3%)
Rent and Inheritance	45 (22.5%)	53 (26.5%)	98 (24.5%)	77 (38.5%)	55 (27.5%)	132 (33.0%)
Others	3 (1.5%)	2 (1.0%)	5 (1.3%)	5 (2.5%)	3 (1.5%)	8 (2.0%)
Total	200 (100.0%)	200 (100.0%)	400 (100.0%)	200 (100.0%)	200 (100.0%)	400 (100.0%)

Source: author's fieldwork
Before adoption: Chi-square = 2.708 and P value = 0.439, not significant at $p < 0.05$
After adoption: Chi-square = 8.071 and P value = 0.045, significant at $p < 0.05$

The second type is land received through rent or lending (locally called *aro*). In this land tenure system, land can be loaned out for brief periods of time from one person or family to another person or family for one or more harvests, partly because the owners of such land lack productive means to cultivate it, and partly because the owners have surplus plots of land that they cannot totally utilize. Usually the land belongs to the giver, and rents over such land are usually redeemed by the recipient in cash after harvest. It is also possible for the community head to give out land under the *aro* system to a settled immigrant. When the latter happens, the land is usually retained by the recipient throughout his/her lifespan, but such land is not automatically transferable to the offspring of the recipient. It is possible, however, for the offspring to request the use of such land from the community leader after the death of the recipient.

As illustrated in Table 4, the respondents are classified according to inheritance (*gado*) and rent/loan/purchase (*aro*) land tenure systems as well as *others*, which covers all the other forms of tenure but refers mostly to another two types of tenure: gift (locally called *kyauta*), in which land is given to an individual as a gift, and hired basis (locally called *riko*), in which the borrowers do not pay for such land. A common thread runs through the adopters and nonadopters, as most of them own all their farmland through inheritance (*gado*).

After technology adoption, the percentages of the adopters that owned all their land through inheritance reduced dramatically, while the percentages of the nonadopters that owned all their land through inheritance decreased marginally. The simple reason for the dramatic reduction was that many of them were able to own their farmland through both inheritance and rentals after the technology adoption. Essentially, an introduction of rental land into the equation suggests that the adopters had extra activities to use land for. This is in spite of the fact that agricultural land markets in the location of the study are underdeveloped, which means that renting of farmland is not a common feature, particularly due to increasing population pressure on land. There are no significant differences between the adopters and nonadopters in the tenure of their farmland before technology adoption. However, after the adoption there are significant differences between the two groups in the tenure of their farmland.

Because most of the land of the respondents is owned through inheritance, as the population has grown, there has been increased fragmentation of their farmland, resulting in both upland and *fadama* landholdings being scattered across different locations in their nucleated settlements. Although this fragmentation provides some equitability in the distribution of land of varying soil types and a reduction of the effect of variations in rainfall, particularly at the beginning and end of the rainy season, it makes it difficult for individual farmers to develop a large area with a combination of tube well and pump technology and leads to a disproportionate amount of time being spent walking from their residence to the different fields.

As Table 5 shows, it is clear that a majority of *fadama* and upland plots are scattered and excessive fragmentation of upland plots is more prevalent than *fadama* land. This is not surprising because *tudu* farmland is essentially rainfed and not tied to specific aquifer conditions. There are no significant differences between the adopters and nonadopters in the location of their farmland prior to technology adoption.

Table 5. Location of farmland of adopters and nonadopters

Location of Farmland	Adopters	Nonadopters	Total
All plots in one area	13 (6.5%)	21 (10.5%)	34 (8.5%)
Upland together, *fadama* scattered	4 (2.0%)	4 (2.0%)	8 (2.0%)
Fadama together, upland scattered	60 (30.0%)	53 (26.5%)	113 (28.3%)
All plots scattered	123 (61.5%)	122 (61.0%)	245 (61.3%)
Total	200 (100.0%)	200 (100.0%)	400 (100.0%)

Source: author's fieldwork
Chi-square = 2.320 and P value = 0.509, not significant at $p < 0.05$

The respondents interviewed own and operate both *fadama* land and upland. It was difficult to obtain the exact number of hectares of *fadama* and upland owned and cultivated by the respondents because of problems of recall and because the respondents have several plots of farmland that are scattered within their communities. Therefore, information was collected on the numbers of plots of *fadama* and upland owned and operated directly by the respondents rather than information on hectares of farmland. Information on the number of plots of farmland is composed of all of the respondents' different

types of land tenure. It was easy for respondents to provide the number of plots of farmland because land is the crucial factor of production upon which their primary livelihood depends. The farmers had little difficulty in pointing out the changes in the number of plots they owned and cultivated.
The numbers of farmland plots are presented in Table 6. There are no significant differences between the adopters and nonadopters in terms of their numbers of different *fadama* and upland plots before the technology adoption. However, after the technology adoption, there are significant differences between the two groups in terms of ownership and operation of their land plots.

Table 6. Average landholdings of the adopters and nonadopters

Landholdings (mean values for sample) (number of plots)	Adopters (N = 200)				Nonadopters (N = 200)				Difference in Landholdings of Adopters and Nonadopters before Adoption	Difference in Landholdings of Adopters and Nonadopters after Adoption
	Before Adoption	After Adoption	Change	%Change	Before Adoption	After Adoption	Change	% Change		
Fadama land owned	3.9 (50.6)	4.0 (54.1)	0.1	2.2	3.8 (50.7)	3.2 (43.2)	-0.6	-15.8	0.1 ((1.01))	0.8* ((4.25))
Fadama land cultivated	3.5 (50.7)	3.6 (53.7)	0.1	2.6	3.3 (50.0)	2.7 (41.5)	-0.6	-17.2	0.2 ((1.39))	0.9* ((5.53))
Upland owned	3.8 (49.4)	3.4 (45.9)	-0.4	-10.7	3.7 (49.3)	4.2 (56.8)	0.5	13.6	0.1 ((0.40))	-0.8* ((-4.46))
Upland cultivated	3.4 (49.3)	3.1 (46.3)	-0.3	-7.6	3.3 (50.0)	3.8 (58.5)	0.5	15.8	0.1 ((0.75))	-0.7* ((-4.22))
Total farmland owned	7.7	7.4	-0.3	-4.4	7.5	7.4	-0.1	-1.3	0.2 ((0.85))	0.0 ((-0.20))
Total farmland cultivated	6.9	6.7	0.1	-2.8	6.6	6.5	-0.1	-1.5	0.3 ((1.32))	0.2 ((0.62))

Source: author's fieldwork
Note: Shares of total land (%) are in single parentheses. Robust z-statistics are in double parentheses.
*** significant at 1%; ** significant at 5%; * significant at 10%

Access to Market by the Adopters and Nonadopters

In order that their access to market could be understood, the two groups were asked to provide information about the main sale points of their farm produce in terms of four ranking categories: (1) farm gate, (2) village or town market, (3) distant market in another state or region of Nigeria, and (4) nonmarket, for those who do not market their farm produce. The typology is based on the fact that farm produce sold in distant markets in major cities in other states or regions of Nigeria yields higher incomes than that marketed in local village or town markets. In turn, farm produce marketed in local village or town markets brings in more money to farmers than that sold at farm gate prices. Therefore, as a measure of differentiating wealthy farmers from poor farmers, farmers who sell most of their farm produce in distant markets tend to be wealthier than other farmers because farmers must have had a bumper harvest and bulky farm produce to take their produce to southern Nigeria for sale. Similarly, farmers who sell most of their farm produce in local village or town markets are considered wealthier than those who sell their farm produce at farm gate prices. Finally, farmers who sell most of their farm produce at farm gate prices are considered wealthier than those who do not market their produce but grow their produce for home consumption.

Table 7. Access to markets by the adopters and nonadopters

Market	Before Adoption			After Adoption		
	Adopters	Nonadopters	Total	Adopters	Nonadopters	Total
Farm gate	61 (30.5%)	60 (30.0%)	121 (30.3%)	42 (21.0%)	52 (26.0%)	94 (23.5%)
Village/town market	96 (48.0%)	113 (56.5%)	209 (52.3%)	110 (55.0%)	121 (60.5%)	231 (57.8%)
Distant market in another state	30 (15.0%)	14 (7.0%)	44 (11.0%)	43 (21.5%)	11 (5.5%)	54 (13.5%)
Don't market	13 (6.5%)	13 (6.5%)	26 (6.5%)	5 (2.5%)	16 (8.0%)	21 (5.3%)
Total	200 (100.0%)	200 (100.0%)	400 (100.0%)	200 (100.0%)	200 (100.0%)	400 (100.0%)

Source: author's fieldwork
Before adoption: Chi-square = 7.209 and P value = 0.066, not significant at $p < 0.05$
After adoption: Chi-square = 26.313 and P value = 0.000, significant at $p < 0.05$

Before the technology adoption, there are no significant differences between the adopters and nonadopters in their access to market. However, after the adoption there are significant differences between the two groups in their access to market (Table 7). Although only very few of the respondents marketed their farm produce in distant markets, it is clear from Table 7 that the percentage of the adopters who marketed their farm produce in distant markets increased after technology adoption.

Estimation of the Effect of Agricultural Technology on Incomes

To quantify the character of the relationship between agricultural technology and incomes, and to estimate the unconditional treatment effect of agricultural technology on incomes, this section utilizes OLS regression analysis and the difference-in-difference model presented in equation (1). The analysis here differentiates between different income sources because the respondents generate disproportionate amounts of income from diverse income sources and livelihoods, which have different effects on welfare of the respondents. All the income portfolios are real incomes corrected for inflation.

The results of the analysis are presented in Table 8. The logarithms of income portfolios are used because of their very likely nonlinearities between incomes and the independent variables and also because they provide easier interpretation of the regression coefficients, as they would give the percentage differences in incomes between adopters and nonadopters of agricultural technology. The coefficient of the unconditional treatment effect of the agricultural technology is positive and statistically significant using farm income from irrigation. This result implies that farmers who adopted agricultural technology received approximately 31.4 percent more farm income from irrigation than the nonadopters on average. Adoption of new agricultural technology tends to have led to a larger increase of agricultural income from irrigation of the adopters than the nonadopters.

Similarly, the coefficient of the unconditional treatment effect of the agricultural technology is negative and statistically significant using nonfarm income. This result indicates that farmers who did not adopt agricultural technology received on average 21.1 percent more nonfarm income than the adopters. Although the coefficients of the unconditional treatment effect of the agricultural technology are statistically insignificant using farm income from rainfed farming and total income, the positive sign associated with these coefficients illustrates that the adopters had a bigger change in farm income from rainfed farming (4.2 percent) and total income (8.9 percent) than the nonadopters.

Table 8. Estimation of the effect of agricultural technology on incomes

	Dependent Variables			
	Log of Total Income	**Log of Farm Income from Irrigated Farming**	**Log of Farm Income from Rainfed Farming**	**Log of Nonfarm Income**
Treatment status (*Ti*) = 1 if the individual is in the treatment group; 0 if the individual is in the control group	-0.061 (-0.75)	-0.029 (-0.34)	-0.023 (-0.28)	-0.028 (-0.32)
Time period (*ti*) = 1 in the posttreatment period; 0 in the pretreatment period	0.044 (0.53)	-0.089 (-1.05)	0.148* (1.76)	0.135** (1.58)
Effect of the agricultural technology = 1 only for the treatment group in the posttreatment period	0.089 (0.77)	0.314*** (2.63)	0.042 (0.35)	-0.211* (-1.71)
Constant term	11.568*** (199.77)	10.553*** (179.18)	10.473*** (176.87)	10.367*** (170.37)
R-squared	0.004	0.016	0.010	0.011
Number of observations	400	400	400	400

Note: T-statistics are in parentheses. *** significant at 1 percent; ** significant at 5 percent; * significant at 10 percent.

Estimation of the Determinants of Income from Agricultural Technology

This section is aimed at identifying the determinants of the three sources of income (farm income from irrigated farming, farm income from rainfed farming, and nonfarm income) by taking all other factors into consideration. The importance of this analysis is twofold: first, to identify those factors and characteristics that somehow cause income to be produced; and second, to pinpoint the relative importance of each of those factors in producing different types of income. This is because income is an outcome that is determined by categories of factors or explanatory variables such as landholdings, labor, harvests, markets, education, and other personal household characteristics.

The logarithms of each of the three sources of income plus total income are regressed on different types of relevant income-producing variables. When characteristics and factors that may cause incomes of the respondents to be produced are included in the OLS regression analysis as presented in Table 9, it becomes evident that the explanatory variables tend to show that the adopters received, on average, approximately 15.4 percent more farm income from irrigation than the nonadopters in the presence of key factors that determine income. This is because the coefficient of the effect of the agricultural technology (δ) is still positive and statistically significant for the farm income from irrigation.

Probably the most interesting finding in Table 9 is that the coefficients of the conditional treatment effect are now all negative using total income, farm income from rainfed farming, and nonfarm income, with only the latter being statistically significant. These results suggest that while the adopters had a bigger change in farm income from irrigation than the nonadopters, the latter tend to have 7.3 percent, 10.1 percent, and 45 percent more total income, farm income from rainfed farming, and nonfarm income, respectively, than the adopters in the presence of key factors that determine income.

Table 9. Estimation of the determinants of income of agricultural technology

	Dependent Variables			
	Log of Total Income	**Log of Farm Income from Irrigated Farming**	**Log of Farm Income from Rainfed Farming**	**Log of Nonfarm Income**
Treatment status (*Ti*) (1 = individual in the treatment group; 0 = individual in the control group)	-0.058 (-1.19)	-0.037 (-0.73)	-0.018 (-0.37)	-0.000 (-0.00)
Time period (*ti*) (1 = posttreatment period; 0 = pretreatment period)	-0.036 (-0.71)	-0.172*** (-3.26)	0.034 (0.68)	0.070 (1.04)
Effect of the agricultural technology (1 = the treatment group in the posttreatment period)	-0.073 (-1.03)	0.154** (2.09)	-0.101 (-1.41)	-0.450*** (-4.19)
Food security (0 = food insecure; 1 = food secure)	0.795*** (16.06)	0.788*** (15.37)	0.773*** (15.55)	0.667*** (9.89)
Markets (0 = no market; 1 = market in village, town, or distant places)	0.039 (0.90)	0.070 (1.54)	0.077* (1.74)	0.062 (1.03)
Harvests (0 = poor harvest/crop failure; 1 = average harvest/good harvest)	0.357*** (7.70)	0.293*** (6.05)	0.364*** (7.81)	0.301*** (4.71)
Irrigated land owned	0.089*** (7.18)	0.113*** (8.85)	0.075*** (6.09)	0.053*** (3.16)
Proportion of irrigated land owned that was cultivated	0.627** (2.36)	0.748*** (2.67)	0.396 (1.50)	0.644* (1.87)
Upland (rainfed) land owned	0.037*** (2.92)	0.026* (1.96)	0.079*** (6.14)	0.025 (1.45)
Proportion of upland (rainfed) land owned that was cultivated	0.568* (1.91)	0.702** (2.25)	0.416 (1.40)	0.563 (1.45)
Age	-0.007*** (-3.51)	-0.003 (-1.24)	-0.003 (-1.45)	-0.007*** (-2.60)
Education (0 = no education; 1 = some form of education)	0.025 (0.61)	0.052 (1.24)	-0.007 (-0.16)	0.105* (1.85)
Household size	0.037 (0.40)	-0.085 (-0.88)	0.044 (0.48)	0.034 (0.29)
Number of adult males in the household (labor)	0.019 (0.20)	0.113 (1.15)	-0.023 (-0.24)	0.044 (0.35)
Number of adult females in the household	-0.075 (-0.79)	0.076 (0.78)	-0.066 (-0.70)	-0.082 (-0.68)
Number of children in the household	-0.030 (-0.32)	0.081 (0.84)	-0.043 (-0.46)	-0.009 (-0.07)
Constant term	10.728*** (59.62)	9.408*** (50.21)	9.425*** (52.34)	9.397*** (38.634)
R-squared	0.658	0.657	0.679	0.452
Number of observations	400	400	400	400

Note: T-statistics are in parentheses. *** significant at 1%; ** significant at 5%; * significant at 10%.

Summarizing, irrigated land owned, proportion of irrigated land owned that was cultivated, rainfed land owned, and proportion of rainfed land owned that was cultivated increased the capacity of the adopters to generate more farm income from irrigation than the nonadopters and thus had a statistically significant positive impact on farm income from irrigation. The perceptions of subjective food security status and yield harvests are found to be positively and statistically related to all the sources of income, suggesting that the adopters had bigger changes in all the sources of their income than the nonadopters based on the perceptions of their food security status and yield harvests. The percentage differences in all the sources of income between the adopters and nonadopters are not statistically significant with regard to household size and to number of adult males, adult females, and children in the household. Although access to markets increased the capacity of the adopters to generate more income than the nonadopters in all the sources of income, increasing access to markets does not have statistically significant impacts on the sources of income with the exception of farm income from rainfed farming.

Estimation of the Effect of Agricultural Technology on Poverty Reduction

Before estimating the effect of agricultural technology on poverty, it should be made clear from the outset that the primary objective of poverty measurement reported in this section is to make comparisons between the adopters and nonadopters of new agricultural technology in the survey villages in Nigeria. There are three main reasons for complementing the analysis in this paper by using a number of poverty measures. The first reason is that the income comparison analysis in the previous section does not really deal with poverty reduction but with interesting changes in income, as it deals with both the well-off farmers and the poor farmers. The second reason is that the income comparison analysis in the previous section concentrates mainly on income portfolios of the respondents without combining all the incomes of the respondents to form summary statistics of their poverty status. The third reason is that the income comparison analysis concentrates mostly on average levels of income, which may, however, mask the differential poverty levels of the respondents.

A basic problem in any work on poverty is how to define the poor and how to measure poverty. In this study, a person is considered poor, in absolute terms, if his income level falls below some minimum level necessary to meet basic needs. This minimum level is called the poverty line. The poverty line approach employed here is based on the classification of the poor and nonpoor adopters and nonadopters in relation to their level of total income. As Nigeria does not have an official poverty line, the approach of earlier poverty researchers on Nigeria such as World Bank (1996), Federal Office of Statistics (1999), Aigbokhan (2000), Canagarajah et al. (1997), and Thomas and Canagarajah (2002) was followed by selecting a poverty line, which is equal to two-thirds of mean per capita expenditure in Nigeria.

Table 10 presents the poverty levels calculated for the adopters and nonadopters using the Foster, Greer, and Thorbecke poverty indexes (see Appendix 1 on how these poverty measures are computed). Looking at the aggregate values of the poverty indexes (poverty headcount, poverty gap, and squared poverty gap), it is apparent that the incidence of poverty, depth of poverty and severity of poverty are higher among the adopters than the nonadopters before adoption of new agricultural technology.

Although the proportions of the population of the adopters and nonadopters defined as poor declined after adoption of new agricultural technology, the aggregate values of the poverty headcount levels of the adopters are higher than those of the nonadopters. It would then appear that there were more poor people among the adopters than the nonadopters both before and after technology adoption.

Table 10. Poverty measures of adopters and nonadopters

Poverty Measures	Adopters (N = 200)				Nonadopters (N = 200)				Difference in Poverty Measures of Adopters and Nonadopters before Adoption	Difference in Poverty Measures of Adopters and Nonadopters after Adoption
	Before Adoption	After Adoption	Change	Percentage Change	Before Adoption	After Adoption	Change	Percentage Change		
Poverty Headcount (%)	62.0	55.5	-6.5	-10.5	52.5	50.5	-2.0	-3.8	9.5	5
Poverty Gap (%)	29.9	26.9	-3.0	-10.0	25.1	25.7	0.6	2.4	4.8	1.2
Squared Poverty Gap (%)	17.8	16.7	-1.1	-6.2	14.7	16.4	1.7	11.6	3.1	0.3

In order to estimate the unconditional treatment effect of the combination of tube well and pump technology on poverty reduction, the standard difference-in-difference approach is followed by estimating a logit model and utilizing only the poverty headcount measure since it simply distinguishes people as poor (when they are below the poverty line by taking the value of 1) or nonpoor (when they are above the poverty line by taking the value of 0).

Table 11. Estimation of the effect of agricultural technology on poverty

	Dependent Variable			
	Poverty Headcount (1 =Poor; 0 =Nonpoor)			
	Coefficient	Standard Error	Chi-Square	P value Significance
Treatment status (*Ti*) = 1 if the individual is in the treatment group; 0 if the individual is in the control group	0.389*	0.203	3.675	0.050
Time period (*ti*) = 1 in the posttreatment period; 0 in the pretreatment period	-0.080	0.200	0.160	0.689
Effect of the agricultural technology = 1 only for the treatment group in the posttreatment period	-0.189	0.286	0.436	0.509
Constant	0.221	0.142	2.410	0.121
Number of observations	400	400	400	400

*significant at $p < 0.05$

As presented in Table 11, the coefficient of the unconditional treatment effect of the agricultural technology is negative and statistically insignificant using the poverty headcount ratios. This result indicates that the differences in poverty outcomes between the technology adopters and nonadopters are not significant. However, the gain in reduction of poverty incidence is disproportionately higher among the adopters than the nonadopters. Similarly, the reduction in income gap among the poor adopters is disproportionately more than the reduction in income gap among the poor nonadopters, while the inequality of the poor tends to be lower among the adopters than the nonadopters.

Estimation of the Effect of Agricultural Technology on Poverty in the Presence of Determinants of Poverty

When all other characteristics and factors that may affect the poverty status of the respondents are included in the logit model, it becomes evident that although the difference in poverty outcomes of the adopters and nonadopters is insignificant, the explanatory variables tend to show that the adopters witnessed more poverty reduction than the nonadopters. This is because the coefficient of the conditional treatment effect of the agricultural technology is still negative using the poverty headcounts.

Table 12. Estimation of the effect of agricultural technology on poverty in the presence of determinants of poverty

	Dependent Variable			
	Poverty Headcount (1 = Poor; 0 = Nonpoor)			
	Coefficient	**Standard Error**	**Chi-Square**	**P value Significance**
Treatment status (*Ti*) (1 = individual in the treatment group; 0 = individual in the control group)	-0.692	0.624	1.229	0.268
Time period (*ti*) (1 = posttreatment period; 0 = pretreatment period)	0.689	0.681	1.024	0.311
Effect of the agricultural technology (1 = the treatment group in the posttreatment period)	-1.296	0.982	1.741	0.187
Food security (0 = food insecure; 1 = food secure)	-0.552	0.752	0.539	0.463
Markets (0 = no market; 1 = market in village, town, or distant places)	-0.044	0.552	0.006	0.937
Harvests (0 = poor harvest/crop failure; 1 = average harvest/good harvest)	-0.318	0.687	0.215	0.643
Log of income from rainfed farming	1.262	1.447	0.761	0.383
Log of income from irrigation	-1.230	1.282	0.920	0.338
Log of nonfarm income	-1.063	1.194	0.793	0.373
Irrigated land owned	-0.199	0.165	1.455	0.228
Proportion of irrigated land owned that was cultivated	5.493	3.268	2.826	0.093
Upland (rainfed) land owned	0.232	0.195	1.411	0.235
Proportion of upland (rainfed) land owned that was cultivated	4.727	4.348	1.181	0.277
Age	-0.032	0.030	1.189	0.275
Education (0 = no education; 1 = some form of education)	0.190	0.546	0.120	0.729
Household size	0.926	0.785	1.389	0.239
Number of adult males in the household	-1.034	0.899	1.322	0.250
Number of adult females in the household	-0.163	0.801	0.041	0.839
Number of children in the household	0.213	0.783	0.074	0.786
Constant	148.593	20.952	50.299	0.000
Number of observations	400	400	400	400

In summary, however, of the variables included in the logit model, the following variables or factors were negative: food security, markets, harvests, income from irrigation, nonfarm income, irrigated land owned, age, and number of adult males and females in the household. Although these characteristics were not statistically significant, they tend to suggest that the agricultural technology led to the reduction in poverty headcount levels of the adopters.

The Effect of Nonfarm Income on Poverty

The analysis here deals with the comparison of the levels of poverty among adopters and nonadopters of technology in the absence of nonfarm income. To do this, calculations of what the poverty measures of the respondents would be if they had not participated in nonfarm activities were estimated. Then the levels of poverty of the respondents in the presence of all income portfolios were compared with the levels of their poverty without nonfarm income to derive the contribution of nonfarm income to poverty. Interpretation of this comparison is easy. If the poverty levels of the respondents in the presence of all income portfolios are higher or superior to their poverty levels in the absence of nonfarm activities, then it can be concluded that nonfarm incomes increase poverty, and vice versa.

A comparison of the data in Tables 10 and 13 shows that nonfarm incomes resulted in a decline in the incidence, depth, and severity of poverty of both adopters and nonadopters. These results suggest that participation in nonfarm activities not only reduced the poverty headcount levels of the respondents but also narrowed their income gap and disproportionately improved the incomes of the poorest respondents.

Table 13. Poverty measures of the adopters and nonadopters without nonfarm income

Poverty Measures	Adopters (N = 200)				Nonadopters (N = 200)				Difference in Poverty Measures of Adopters and Nonadopters before Adoption	Difference in Poverty Measures of Adopters and Nonadopters after Adoption
	Before Adoption	After Adoption	Change	Percentage Change	Before Adoption	After Adoption	Change	Percentage Change		
Poverty Headcount (%)	77.0	63.5	-13.5	-17.5	72.0	66.5	-5.5	-7.6	5	-3
Poverty Gap (%)	42.3	35.0	-7.3	-17.3	37.3	37.6	0.3	0.8	5	-2.6
Squared Poverty Gap (%)	27.5	23.2	-4.3	-15.6	23.4	25.8	2.4	10.3	4.1	-2.6

5. CONCLUSION

This paper has explored the impact of new agricultural technology on poverty reduction. Using OLS regression analysis and the double difference method to estimate the unconditional treatment effect of new agricultural technology on incomes confirms that technology adopters received a statistically significant and larger increase in agricultural income from irrigation than the nonadopters on average even in the presence of key factors that determine income. On the other hand, the nonadopters tend to have bigger changes in other sources of income such as rainfed agriculture and nonfarm activities than the adopters in the presence of key factors that determine income.

Although there were disproportionately more poor people among the adopters than the nonadopters both before and after technology adoption, the technology adopters fared slightly better than the nonadopters in terms of poverty reduction. In other words, technology adoption led to a *slight* reduction in poverty headcount levels of the adopters and also narrowed their income gap and *slightly* improved the income of the poorest adopters over the nonadopters.

Participation in nonfarm activities noticeably reduced poverty levels of both the technology adopters and nonadopters however poverty is measured. This shows that nonfarm income not only plays a significant role in total income but is also significantly useful in reducing poverty. Overall, the differences in poverty status between the technology adopters and nonadopters are alarmingly modest, indicating that technology adoption did not substantially translate to poverty reduction for its adopters. The key factors that are probably responsible for the modest differential poverty reduction between the two groups are identified as invasion of Quelea Quelea bird pests; conflict over use of natural resources; flooding problems; invasion of weeds, particularly Typha weed; marketing constraints; and lack of access to complementary agricultural inputs and services.

The findings of the paper indicate that participation in agricultural technology does not automatically lead to the reduction in poverty headcount levels and does not disproportionately improve the income of the poorest adopters in comparison with the nonadopters. Although new agricultural technologies have a potential to lead to poverty reduction and increase food security, this does not mean that poor African countries should invest more in such technologies without consolidating the technical improvement of farmers where necessary. An effort toward introducing new agricultural technologies in Africa should go hand in hand with increasing access of specific technology adopters to markets, education, and land. To ensure the sustainability of new agricultural technologies in Africa, it is important to enrich farmers' understanding and know-how of these new technologies.

APPENDIX: FOSTER, GREER, AND THORBECKE POVERTY INDEXES

Although many aggregate poverty measures have been proposed in the poverty literature such as the Sen index (Sen 1976), the three most widely used measures of income/consumption quantitative poverty analysis are the poverty headcount ratio, the poverty gap, and the squared poverty gap or poverty severity. This is because these three poverty indexes satisfy many of the basic desirable properties of poverty measures, particularly the property of being additively decomposable with population share-weights. These three most widely used poverty indexes are usually expressed as members of a class of measures proposed by Foster, Greer, and Thorbecke (FGT; 1984). These three poverty measures are defined from P_α indexes of poverty as follows:

$$P_\alpha = \frac{1}{n}\sum_{i=1}^{q}\left(\frac{z-y_i}{z}\right)^\alpha \qquad (1)$$

where individuals have been ranked from the poorest (*i=1*) to the richest (*i=n*, where *n* is the population size), where *q* is the number of individuals defined to be poor, z is the poverty line, *yi* is the income/expenditure of person *i*, and *α* is a parameter reflecting the weight placed on the welfare levels of the poorest among the poor or what is called measure of "aversion to inequality." The three popular measures of income/consumption poverty measurement tell us different things about the extent and nature of poverty from the FGT index as follows.

The Poverty Headcount Ratio (P_0)

The headcount ratio measures the incidence of poverty (the proportion of the population defined to be poor), and it is obtained for the special case α= *0* as follows:

$$P_0 = q/n. \qquad (2)$$

This is simply the number of poor people divided by the total population. The headcount ratio fails to account for the degree of poverty by ignoring the extent of the shortfall of incomes of the poor from the poverty line. For instance, the headcount ratio will remain the same when there is a reduction in the income of all the poor without affecting the income of the rich if the poverty line is relative. In other words, the headcount ratio will be unaffected by a policy that makes the poor even poorer since it is not sensitive to distribution of income among the poor. Moreover, two societies may have the same headcount ratio, but the poor in one society may be much poorer than the poor in the other society (IFAD 2001). Yet, it appears to be the mainstay of poverty analysis on which policies targeted to reduce poverty are based (Litchfield 1999).

The Poverty Gap (P_1)

The poverty gap measures the aggregate shortfall of the income/consumption of the poor from the poverty line (the depth of poverty). With special case *α*= 1, the FGT index becomes the poverty gap and can be written as:

$$P_1 = \frac{q}{n}\frac{z-\overline{y}^p}{z} \qquad (3)$$

where $\overline{y}_p$ stands for the mean value of *yi* among the poor. The poverty gap measure has an advantage over the headcount ratio in the sense that it will be increased when there is income transfer from poor to nonpoor, or from poor to less poor who thereby become nonpoor. Although the poverty gap index takes both the incidence and depth of poverty into account, it is insensitive to inequality among the poor. For instance, if a poor person spends 10 Nigerian naira a day more but an even poorer person 10 naira fewer, neither poverty incidence nor poverty depth will increase, and yet we know that poverty has become worse.

The Squared Poverty Gap (P_2)

The squared poverty gap measures the severity or intensity of poverty by giving more weight to the poorest. It does this by weighting each poor person by the square of his/her proportionate shortfall below the poverty line. With special case $\alpha = 2$, the FGT index becomes the squared poverty gap, and it can be written as:

$$P_2 = \frac{q}{n}\left[\left(\frac{z-\overline{y}_p}{z}\right)^2 + \left(\frac{\sigma_p}{z}\right)^2\right] \qquad (4)$$

where σ_p is the standard deviation of *yi* among the poor. This measure takes account of the incidence of poverty, the depth of poverty, and the inequality among the poor. It rises when the number of poor people increases, or the poor get poorer, or the poorest get poorer in comparison with other poor people. We might want to prefer the squared poverty gap measure to others, but in practice it is of interest to look at all three measures. It should be noted that these poverty measures take values between 0 and 1, with numbers close to 0 indicating little poverty and those closer to 1 suggesting high poverty. Also, as the value of α increases for the FGT class, so does the (relative) weight placed on the poorest among the poor.

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