

# Impact of Irrigation on Farm Household Diet Quality: Evidence from Ethiopia

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# **Impact of Irrigation on Farm Household Diet Quality: Evidence from Ethiopia**

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## Abstract

Irrigation could theoretically affect farm households' nutritional status in two directions. On the one hand, irrigation may improve nutritional status by boosting farm productivity and household income. On the other hand, it may deter diet quality by shifting farmers' attention from nutrition-rich food to cash crops. This study examines the impact of irrigation schemes on farm households' nutritional status using nationally representative data from Ethiopia. Using the endogenous switching regression model, the study shows that irrigation improves diet quality. In addition, the study also identifies the production of micronutrient-rich crops such as vegetables and fruit and the adoption of productivity-enhancing inputs as the main pathways through which irrigation affects dietary quality. Hence, irrigation can be considered a viable instrument to enhance the diet quality of smallholders, and efforts should be made to tackle constraints that impede the adoption of irrigation technologies.

**Keywords:** irrigation, nutrition, selection model, impact evaluation, Ethiopia

# 1. Background and Justification of the Study

According to the latest report on the state of food security and nutrition, approximately 10% of the global population is undernourished (FAO et al., 2021). The problem appears to be escalating in Africa, where approximately 21% of the population is undernourished (Global Nutrition Report, 2018). This shows that more effort remains to be made in the region to end hunger, ensure food security, and enhance nutritional status, which are part of the Sustainable Development Goals (SDGs).

Ethiopia is one of the countries in the region where chronic undernutrition is widespread. Approximately a quarter of the population is estimated to be food insecure. More than half of the population consumes four or fewer food groups out of seven, and starchy staples account for more than 70 percent of the total calorie consumption (WFP & CSA, 2019). Relatedly, per capita vegetable and fruit consumption in the country is 50.2 and 3.5 kg per year, respectively, which are far below the 146 kg recommendation of the WHO. Strikingly, the problem of malnutrition in the country is not sensitive to wealth status, as a quarter of children from the highest wealth quintile also struggle with stunting, and only 16% of children from the wealthiest families are receiving a minimum acceptable diet (Feed the Future, 2019; WFP & CSA, 2019).

The country has been working with its partners to establish nutrition-related interventions. For example, the second National Nutrition Program, which was developed in 2015, aims to integrate nutritional needs with the agricultural sectors to end hunger by 2030.<sup>1</sup> Since the vast majority of poor and undernourished people depend on small-scale agriculture to support their livelihoods, improving the performance of the sector can play a vital role in eradicating poverty and malnutrition.

As argued by Haddad et al. (2016), examining the performance of the agricultural sector from the perspective of supporting healthier diets is urgently needed to inform nutrition-sensitive agriculture strategies. Accordingly, numerous studies have explored the linkages between agriculture and nutrition in recent years, mostly in developing countries.<sup>2</sup> Among them, the vast majority (including Tesfaye & Tirivayi, 2020; Hirvonen & Hoddinott, 2017; Jones, 2015; Sibhatu & Qaim, 2018) studied the link between

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<sup>1</sup>The document can be accessed at <http://extwprlegs1.fao.org/docs/pdf/eth190946.pdf>

<sup>2</sup>See Ruel et al. (2018) for a comprehensive review of the relationship between agriculture and nutrition.

farm production diversity and the quality of household diet.<sup>3</sup> Others, such as Carletto et al. (2017) and Ogutu and Qaim (2019), examined the role of commercialization on diet quality and nutritional security.

However, as rigorously reviewed by Shankar et al. (2019), the research base on the nutrition implications of agricultural asset ownership is thin and incomplete. In particular, as observed by Balasubramanya and Stifel (2020), studies that explore the link between irrigation use and rural welfare remain unexpectedly undeveloped. They argued that the great majority of existing studies treat water as a given input or focus on the management aspects of the resource. Nevertheless, since the degree of substitutability between water and other crop inputs is very low, a separate analysis is required to examine the impact of irrigation on the welfare status of farm households.

This being the case, studies that establish an empirical link between irrigation use and nutritional security are scarce. In addition, the few available studies are inconclusive and provide two different lines of arguments. Passarelli et al. (2018), Alaofè et al. (2016), and Bhagowalia et al. (2012) argue that irrigation can improve nutritional status either by allowing farmers to produce (and consume) nutritious foods, including micronutrient-rich vegetables and fruits, or it enables them to purchase nutritious foods due to their income increment through increased output and diversion to high-value crops. Contrary to these arguments, others such as Shively et al. (2012) argue that there could be a potential trade-off, as irrigation would cause a shift in the cropping pattern by moving farmers' attention away from nutrition-rich food to not-so-nutritious cash crops. In line with this, Kafle et al. (2021) and Hagos et al. (2009) showed that cereals and pulses are the most important crops in Ethiopia's rain-fed system, whereas horticultural crops are widely grown in the irrigation system.<sup>4</sup>

Nonetheless, most of the existing studies either argue without empirical support or fail to account for selectivity bias. For instance, Hagos et al. (2017) did not address the issue of selectivity bias. However, irrigation use decisions may not be random. Hence, if, for instance, resource-rich farmers are more likely to use irrigation, as shown by Passarelli et al. (2018) and Kafle et al.

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<sup>3</sup> See Sibhatu and Qaim (2018) for a review of studies that examined the linkage between agricultural production diversity and diet quality.

<sup>4</sup>Hussain and Hanjra (2004) also highlight the role of irrigation in shifting farmers' attention toward a market-oriented production system. Similarly, Hagos et al. (2008) argued that small-scale irrigation is a viable option for promoting a market-oriented production system in Ethiopia, as environmental risks, such as rainfall variability, are among the main reasons that trap farmers in the production of low-risk/low-return food grains. High-value crops, such as horticultural crops, are expected to have the highest long-term economic potential (Hagos et al., 2016). Carletto et al. (2011), Euler et al. (2017), and Meng et al. (2020) show cash crops raise household income and living standards.

(2021), they may have better nutritional status even in the absence of irrigation. Alaofè et al. (2016) relied on a few sample sizes taken from four villages, which limits the generalizability of their findings to other areas.

This study adds to the existing literature by providing information on the impact of irrigation on diet quality using nationally representative data from Ethiopia. There are pertinent reasons to focus on Ethiopia for this study. First, food insecurity and malnutrition are widespread and continue to be among the major public health problems in the country. Second, the government of Ethiopia (GoE) has given due attention to developing the agriculture sector by investing in irrigation infrastructure. In the country, the area of land covered by irrigation exceeded 2.34 million hectares in 2015, and the GoE allocated a substantial amount of the national budget to increase this coverage to 4.14 million hectares by the end of 2020 (NPC 2016).<sup>5</sup> Studying the impacts of irrigation schemes on the welfare status of farming households may contribute to charting sound policies for future irrigation development and to justifying whether irrigation can be considered a viable instrument to enhance nutrition security for Ethiopia and beyond.

The remaining sections of the paper are organized as follows. Section 2 presents a conceptual framework that indicates the possible pathways through which irrigation can affect nutrition. Section 3 provides information about the data used in this research and the techniques applied to address the objective of the study. Section 4 presents and discusses the results obtained from different models, and the last section presents conclusions and recommendations.

## 2. Conceptual Framework

Good health is a function of good nutrition, and good nutrition relies on agriculture (Thomas et al., 2015). Accordingly, several studies have been carried out to comprehend the impact of improved agricultural practices and new technologies on nutrition security. Out of them, this section reviews those studies that enable us to construct a conceptual framework that explores the possible pathways by which irrigation can affect nutritional outcomes.

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<sup>5</sup> During the period, the total government budget was estimated to be 2.3 trillion Ethiopian Birr (ETB), with ETB 1.3 trillion allocated for capital investment. The infrastructure sector accounted for approximately 48.4 percent of the total capital investment, with 21.6 percent going to irrigation and energy (NPC, 2016). According to the most recent estimates, the country's irrigated agricultural area covers 3.07 million hectares.

## **Impact of Irrigation on Nutritional Security through Own Production**

Irrigation improves the availability and accessibility of food by improving farm productivity, encouraging the adoption of agricultural innovations, enabling portfolio diversification, and increasing cropping seasons per year. For instance, the meta-analyses carried out by Du et al. (2018) and Zheng et al. (2019) documented that irrigation can increase crop yield by 19.3% and 30.5%, respectively. Colli (1992) and Rathore et al. (2017) also highlight the role of irrigation in improving agricultural productivity. However, Makombe et al. (2007) found rain-fed farms in Ethiopia to be more technically efficient than irrigated plots. Gebregziabher et al. (2012) also found a similar result, but they re-estimated separate production frontiers for irrigated and non-irrigated fields and showed that the frontier for irrigated plots is higher than that of rain-fed plots, although the latter are more technically efficient.

Irrigation can also increase food production by boosting farmers' confidence in adopting productivity-enhancing agricultural technologies. Agricultural technologies are usually adopted jointly as complements or supplements. Similarly, irrigation can encourage farmers to adopt productivity-enhancing technologies, such as improved varieties and agrochemicals (Launio et al., 2018; Gebregziabher & Holden, 2011; Abdoulaye and Sanders, 2005). Numerous studies, including Teklewold et al. (2013) and Manda et al. (2016), show that adopting multiple technologies provides a higher yield gain than adopting technologies in isolation.

Irrigation can also empower farmers to produce crops multiple times per year and enables crop diversification by increasing cropping intensity (Buisson & Balasubramanya, 2019). This production diversification helps to improve diet diversity (Thomas et al., 2015; Domènech, 2015; Tesfaye & Tirivayi, 2020). It also gives confidence to farmers to switch from low-risk/low-return subsistence farming to cash crops, including high-value and water-intensive crops (Hussain and Hanjra, 2004; Kafle et al., 2021 and Hagos et al., 2009).

Irrigation can also enable farmers to diversify their portfolios, even by incorporating livestock production, since the accessibility of water supports fodder production and supplies drinking water for livestock. This will, in turn, increase the availability of animal source foods, which significantly improves diet quality (Rawlins et al., 2014).

## **Impact of Irrigation on Nutritional Security through Market Participation**

Improved agricultural productivity, a move to high-value crops, and the potential to produce more than once a year are all expected to boost irrigation

users' earnings. Li et al. (2020), Gebregziabher et al. (2009), Garbero & Songsermsawa (2018) and Huang et al. (2005) support this argument. Among them, Gebregziabher et al. (2009) from Ethiopia show that non-irrigating households have less than half the income of irrigating households. This improvement in farm income is expected to boost the ability to access food. For instance, Ogutu et al. (2017) showed that the market participation of smallholder farmers significantly increases the consumption of food purchased without reducing the amount of nutrients consumed from their production. The role of irrigation on diet quality by improving farm income was also discussed by Passarelli et al. (2018).

### **Impact of Irrigation on Nutritional Security through Gender Empowerment**

As fetching water is mainly the responsibility of women and children in most rural areas, the availability of water due to irrigation can reduce the work burden on women (Domènech, 2015). Hence, they can allocate more time for food preparation and sanitation. For example, Ahmed et al. (2017) also showed an inverse association between time spent fetching water and diet quality. Particularly, if women have control over the income and the food generated via irrigation, the chance of improving the diet quality is higher (Upadhyay et al., 2005). However, irrigation may also encourage household members to devote more time to farming or other off-farm income-generating activities, potentially altering their time allocation. As a result, the direction of the effects of this mechanism on diet quality is an empirical question.

### **Impact of irrigation on nutritional security through health aspects**

Better accessibility of water within the household due to irrigation can also result in better hygiene and sanitation practices. As argued by Van Der Hoek et al. (2002), the accessibility of water might be much more important in rural areas than the quality of water for health.

However, to realize all the benefits of irrigation listed above, there must be a regular water supply and proper management. If appropriate management practices are not put in place, they may cause harmful effects on health and the environment. In addition, there must be institutional support, such as extension, credit, and market information, for farmers. Empirical findings (e.g., Wang, 2010; Alcon et al., 2011) also indicated that socioeconomic variables such as family size, off-farm activity, risk preference, education and age of the household head, farm size, and land tenure affect the decision of farmers to use irrigation. Based on the above empirical reviews, Fig.1 outlines the pathway and intermediaries through which irrigation can affect nutrition security.

### 3. Research Methodology

#### The Data

This research uses the comprehensive and nationally representative Ethiopian Socioeconomic Survey, which was administered by the Living Standards Measurement Study-Integrated Surveys of the World Bank in 2013/2014. The survey produced rich data at the household, plot, and village levels by covering 433 enumeration areas (EAs) across all regional states of the country.<sup>6</sup> The sample respondents were selected using a two-stage probability sample. In the first stage, EAs were selected using simple random sampling. The location of EAs in the country is indicated in Fig.2. This stage was followed by the selection of households to be interviewed from each EA.<sup>7</sup> This study uses data collected from rural EA.

#### Indicator of Household Nutrition

This study uses household Diet Diversity Scores (DDS) as an indicator of nutrition status. It is believed that increasing the variety of foods across and within food groups ensures adequate intake of essential nutrients and promotes good health. Studies have also shown that diet diversification is positively correlated with nutrient adequacy (both macro-and micronutrients) and dietary quality (Moursi et al., 2008). It also improves health outcomes, including birth weight (Rao et al. 2001) and child anthropometric status (Arimond & Ruel, 2004). A recent study from Ethiopia by Mekonnen et al. (2020) also found DDS to be a strong predictor of nutrient adequacy.

Dietary diversity is usually measured by summing the number of foods or food groups consumed over a reference period, and this period usually ranges from 1 to 7 days. This study calculates DDS based on a 7-day food consumption recalls of 12 food groups of the FAO guideline, which comprise "vegetables; white tubers and roots; cereals; legumes; nuts and seeds; fruits; oils and fats; meat; fish and fish products; milk and dairy products; eggs; sweets and sugars; condiments, spices, and beverages".

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<sup>6</sup> The survey did not cover the nonsedentary population of three zones of Afar and six zones of Somali regional states.

<sup>7</sup> Detailed information on sampling procedure, data collection instrument, the types of data collected and related information can be accessed at <http://microdata.worldbank.org/index.php/catalog/2783>

## Method of Data Analysis

Estimating the impact of irrigation on DDS

The relationship between irrigation use and its impact on nutritional status can be modelled, along with a vector of other explanatory variables ( $X$ ) and their coefficients ( $\psi$ ), as follows:

$$N_i = X_i\psi + \Omega I_i + \varepsilon_i \quad (1)$$

where  $N_i$  stands for the outcome variables,  $I_i$  denotes a binary variable indicating whether the farmer uses irrigation or not and  $\varepsilon_i$  represents the random error term. Hence, the impact of irrigation on the outcome variable would be equal to  $\Omega$  if users and nonusers were randomly assigned. However, users and nonusers may not be randomly distributed between the two groups. For example, irrigation users and nonusers may differ based on their wealth status (Passarelli et al. 2018 and Kafle et al. 2021), physical and human capital endowments (Koundouri et al. 2006; Hunecke et al. 2017), or risk-taking behavior (Torkamani & Shajari 2008). In this case, the mean value of the outcome indicators of the two groups differed even in the absence of the treatment (i.e., irrigation). Hence, this initial bias has to be solved. As selection bias may arise due to systematic differences in terms of both observable and unobservable characteristics, this study adopted the endogenous switching regression model (ESR) to control for these heterogeneities.

The implementation of the ESR framework involves two stages. In the first stage, the selection equation that shows the decision to use irrigation is modelled. This stage can be specified as follows:

$$I_i^* = X_i\beta + \varepsilon_i \text{ with } I_i = \begin{cases} 1 & \text{if } I_i^* > 0 \\ 0 & \text{otherwise} \end{cases} \quad (2)$$

where  $I_i^*$  is the latent variable for the decision to use irrigation,  $I_i$  is its observable counterpart<sup>8</sup>, and  $X_i$  are vectors of observed characteristics determining farmers' decisions to use irrigation.  $X_i$  includes household, community, and environmental factors. As environmental factors, drought index and soil fertility indicators are included. The drought index is measured using the standardized precipitation evapotranspiration index (SPEI), and

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<sup>8</sup> In this study, a household is considered as an irrigation user if irrigation is used for agricultural activities in one of the plots operated by the farmer. Table 10 provides a list of crop items produced using irrigation

soil fertility is proxied by the availability of soil nutrients.<sup>9</sup> Controlling for soil fertility helps to account for whether farmers residing in areas that are more suitable for irrigation are cultivating higher value crops given better land quality.

In the second stage of the ESR framework, two outcome regression equations faced by the farmers—to use irrigation (Regime 1) and not to use (Regime 2)—conditional on adoption are estimated. The equations can be expressed as:

$$\text{Regime 1 (user): } D_{1i} = \alpha_1 J_{1i} + e_{1i} \quad \text{if } I_i = 1 \quad (3a)$$

$$\text{Regime 2 (nonuser): } D_{2i} = \alpha_2 J_{2i} + e_{2i} \quad \text{if } I_i = 0 \quad (3b)$$

where  $D_i$  is the outcome variable (diet diversity score) in each regime,  $J_i$  represents a vector of exogenous variables expected to affect the outcome variable, and  $e_i$  are random errors. The error terms given under this framework are assumed to have a trivariate normal distribution, with zero mean and a nonsingular covariance matrix, which can be expressed as:

$$\text{cov}(e_{1i}, e_{2i}, u_i) = \begin{pmatrix} \sigma_{e1}^2 & \cdot & \sigma_{e1u} \\ \cdot & \sigma_{e2}^2 & \sigma_{e2u} \\ \cdot & \cdot & \sigma_u^2 \end{pmatrix}$$

where  $\sigma_u^2$  represents the variance of the error term in the selection equation (adoption of irrigation, for this case), and  $\sigma_{e1}^2$  and  $\sigma_{e2}^2$  are the variances of the error terms in the outcome functions (DDS equation). Correspondingly,  $\sigma_{e1u}$  and  $\sigma_{e2u}$  represent the covariance of  $u_i e_{1i}$  and  $u_i e_{2i}$  (Khonje et al. 2015). The expected values of  $e_{1i}$  and  $e_{2i}$  conditional on the sample selection are given by:

$$E[e_{1i} | I_i = 1] = \sigma_{e1u} \frac{\phi(\beta x_i)}{\Phi(\beta x_i)} = \sigma_{e1u} \lambda_{1i} \quad (4)$$

$$E[e_{2i} | I_i = 0] = \sigma_{e2u} \frac{\phi(\beta x_i)}{1 - \Phi(\beta x_i)} = \sigma_{e2u} \lambda_{2i} \quad (5)$$

where  $\phi(\cdot)$  stands for the standard normal probability density function,  $\Phi(\cdot)$  is the standard normal cumulative density function, and  $\lambda_{1i}$  and  $\lambda_{2i}$  represent the inverse Mills ratio calculated from the selection equation (Asfaw et al., 2012).

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<sup>9</sup> SPEI is accessed from <https://spei.csic.es/> and availability of soil nutrients is obtained from <https://webarchive.iiasa.ac.at/Research/LUC/External-World-soil-database/HTML/>

The average treatment effect on the treated (ATT) and the untreated (ATU) can be estimated from the above framework by comparing the expected values of the outcomes of users and nonusers in actual and counterfactual scenarios. Accordingly, ATT is computed as the difference between the expected outcome of irrigation users and the counterfactual case that they did not use, whereas ATU is computed as the difference between the expected outcome of nonusers and the counterfactual case that is the expected value of the outcome indicator if they decided to use irrigation.

For the endogenous switching models to be identified, it is important to include a selection instrument. Accordingly, '*the slope of the plot*' is chosen as a selection instrument by conducting a falsification test following Di Falco et al. (2011). The test result, which is presented in Table A5, indicates that the selected instrument is a viable instrument as it is strongly correlated with the decision to use irrigation, and it is found not to be correlated with the outcome variable for the nonusers. Because the Ethiopian land tenure law prohibits landholders from selling agricultural land, selection bias is negligible.

Farmers' decision to use irrigation is significantly influenced by the slope of the plot (Pokhrel et al., 2018). Walker (1989) also listed the slope of the field and its uniformity as the most important determinants for using irrigation. As the slope of the plot affects the water distribution, steeper fields require additional energy (and cost) to move water across areas in the plot. Depending on the direction of the water source, irrigation can also induce erosion and affect water use efficiency. Hence, the slope of the plot can affect farmers' decisions to use irrigation. However, the instrumental variable is not irrefutable. It is possible, for example, that slope would affect agricultural production through other avenues, so the findings of the study should be interpreted with this caveat in mind.

### **3.1.1. Exploring the mechanisms**

After evaluating the impacts of irrigation on diet quality, the study explores the impact pathways outlined in the preceding section, depending on data availability. The most common technique for examining impact mechanisms in existing studies is to examine the relationship between the proposed mechanisms and the independent variable. In this strategy, a variable is considered to have some mediation effects if the independent variable substantially predicts the expected mediator. However, Acharya et al. (2016) illustrate that this technique might lead to biased estimates and propose a strategy that treats the problem as a system of equations. In line with this, recent studies, including Pace et al. (2022), Passarelli et al. (2018), and Cockx et al. (2018), explored impact pathways by solving structural equations. As

both techniques have their own strengths, this study combines the two approaches. Specifically, the study combines the propensity matching score technique (PSM) with *Stata's 'medsem'* package that solves systems of equations to explore the possible mechanisms.

PSM helps to adjust for initial differences between the two groups by matching each irrigation user to nonusers based on similar observable characteristics (Rosenbaum & Rubin, 1983). Therefore, the first step in PSM is to predict the propensity scores for each observation using characteristics that are not affected by the treatment variable. This stage is followed by imposing the common support region and the identification of an appropriate matching estimator. The fourth step is checking for matching quality, and if the matching quality is satisfied, the average treatment effect on the treated (ATT) can be specified as the mean difference in the outcome indicator of the irrigation users matched with nonusers who are balanced on the propensity scores and fall within the region of common support and can be expressed as:

$$E[Y(1)|I = 1] - E[Y(0)|I = 0] = \tau_{ATT} + E[Y(0)|I = 1] - E[Y(0)|I = 0] \quad (6)$$

where  $\tau_{ATT}$  is the treatment effect on the treated,  $Y$  is the outcome indicator (DDS), and  $I$  is a dummy variable that indicates whether the household has used irrigation or not. Both terms on the left-hand side are observable, and ATT can be identified if and only if  $E[Y(0) | I = 1] - E[Y(0) | I = 0] = 0$ . when there is no self-selection bias.

The other technique used to identify the mediators is solving the system equations using *Stata's 'medsem'* package. Under this approach, a variable must fulfil certain preconditions to be considered a mediator (Mehmetoglu 2018; Zhao et al., 2010). After solving the system equation, the independent variable has to have a significant effect on the mediating variable ( $X \rightarrow M$ ) (for our case, irrigation use has to have a statistically significant effect on the production of noncereals, for example). In the second step, the mediating variable has to have a statistically significant effect on the outcome variable ( $M \rightarrow Y$ ). There will be no mediation effect if either of the above two conditions is not fulfilled, and there could be 'some' mediation if both are fulfilled. Specifically, to have a 'complete' mediation effect, in addition to the above two conditions, Sobel's z-test<sup>10</sup> must be statistically significant, and the

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<sup>10</sup>The Sobel z-test determines if an independent variable has an indirect effect on the dependent variable mediated by another variable. To do so, it tests the hypothesis that there is no statistically significant difference between the total effect and the direct effects of the independent variable after accounting for the influence of a potential mediator (Allen, 2017).

coefficient of the independent variable on the dependent variable must be statistically insignificant ( $X \rightarrow Y$ ); otherwise, there will be partial mediation. Detailed theoretical and empirical descriptions of the model can be found in Mehmetoglu (2018) and Zhao et al. (2010).

## 4. Results and Discussions

### **Descriptive statistical results of the variables used in the models**

The description and summary statistics of the variables used for this study are presented in Table A1 and Table 1. As indicated in Table 1, 75% of the households are headed by a male. The average age of the household head is approximately 46 years, and 38% of them can read and write at least. On average, households own 1.24 hectares of land and 4.7 units of livestock measured in tropical livestock units (TLU). The average family size, measured in terms of adult equivalent, is four. Regarding their access to institutions, 20% of them have accessed credit, and 47% of them live in the village where there is a weekly market. On average, they travel approximately 17 km to reach the nearest major road. The result from a simple ttest implies the difference in terms of some of the characteristics considered in the study as statistically significant. These variables include location dummy, demographic characteristics (sex and family size), wealth status (livestock and land size), and access to the market.

Regarding the outcome variable, the mean DDS is 5.697, which is above the minimum acceptable diet (four or more food groups). However, 26% of the households reported consumption below the minimum acceptable diet. As shown in Table A2, there is also visible heterogeneity between irrigation users and non-users in terms of the consumption of different food groups. Cereal is widely consumed by both groups, with more than 97% of non-users and 99% of users reporting intake. The consumption of beans, beef, and fish is common in non-user households, whereas vegetables, fruits, and dairy products are common in user households. This is in line with Alaofè et al. (2016), who showed that irrigation increases the consumption of vegetables and fruits, and Hagos et al. (2009), who highlighted the prevalence of cereals and pulses in Ethiopia's rain-fed system.

Regarding the share of irrigation users, 12% of households are irrigation users. Rivers and ponds are the main sources of irrigation water, as 68% and 7% of irrigation users cited them as their main source of irrigation water. Among cereal crops, maize and sorghum are the major crops that use irrigation. The most commonly irrigated fruits are bananas, lemons, and oranges, while the corresponding crops from the vegetable groups are kale, onions, and

tomatoes. Likewise, coffee and chats are the most important irrigation user cash crops. Tables A3 and A4 summarize crops grown using irrigation and irrigation water sources, respectively.

### **Econometric Results**

#### Estimating the impact using the Endogenous Switching Regression

The result of the full information maximum likelihood estimates of the endogenous switching model is presented in Table A6. The first column presents the coefficient of the selection equation, and DDS\_1 and DDS\_0 present DDS equations for irrigation users and nonusers, respectively.<sup>11</sup> Although identifying the coefficients of the equations of DDS for irrigation users and nonusers is not the aim of the paper, the result presented in the table illustrates the presence of heterogeneity in the determinant of the diet diversity score equation of the two groups. This shows that estimating the DDS equation using simple regression analysis by incorporating a dummy variable to indicate irrigation use cannot account for the heterogeneities between the two groups. In addition, the significance of the estimated coefficients of the correlation term *rho* presented in the table implies that the hypothesis of the absence of selectivity bias is rejected. Indeed, the endogenous switching regression model is adapted to control for such types of sample selection bias and to account for heterogeneity that exists between the two groups.

After fitting the ES models, the predicted values of the outcome indicators are used to estimate the average treatment effect of using irrigation on the treated (ATT) and untreated (ATU) groups. The results are presented in Table 2. As presented in the table, irrigation increases DDS by an average of 2.14 units for users. Furthermore, the results also show that if nonusers had adopted irrigation technology, their DDS would have increased by an average of 0.34. This result is consistent with the existing knowledge. For example, Mekonnen et al. (2019) and Baye et al. (2019) show a positive association between households' nutritional status and irrigation in Ghana and Ethiopia.

### **Mechanisms**

Tables 3 and 4 present the results from the analysis of the mechanisms obtained from the PSM and system equation-based models, respectively. The study examines farmers' land allocation decisions, spending on nutritious food items, adoption of commercial inputs, portfolio diversification, and time

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<sup>11</sup> The *Stata* command '*movestay*' is used to run the ESR model and a detailed description of the procedure can be found at Lokshin and Sajaia (2004).

spent by female household members fetching water as plausible mechanisms.

The result from the PSM technique shows that irrigation increases the probability of the production of non-cereals and the adoption of commercial inputs. However, the effects on spending on nutritious food items, livestock size, and time spent by female household members fetching water are not statistically significant. As presented in the table, irrigation increases, on average, the probabilities of producing noncereal crops by approximately 19% compared with their non-irrigated counterparts. Similarly, it increases the likelihood of production of either vegetables or fruits by 25 to 29 % compared with their non-user counterparts. Related works by Alaofè et al. (2016) and Naylor et al. (2011) also show that irrigation increases the production and consumption of fruits and vegetables in SSA. Irrigation use also increases the probability of adoption of fertilizer up to nine percent compared with their non-user counterparts. The complementarity between irrigation use and the adoption of commercial inputs, such as inorganic fertilizer, has been documented in previous studies (Gebregziabher & Holden 2011; Abdoulaye & Sanders, 2005). The adoption of such inputs is expected to enhance nutritional status (Teklewold et al., 2019). Sensitivity analysis was conducted for all significant outcome variables, and the results are presented in Tables A7 to A9.

Consistent with the PSM model findings, the result obtained by solving the system equations also identified the production of noncereal crops and the adoption of new technologies as possible mechanisms (Table 4). One of the additional features of this technique is that it also calculates the contributions of the mediators on the total effects by computing the ratio between the indirect and total effects. For example, the result shows that approximately 44% of the effects of irrigation on diet diversity score are mediated by the production of fruits and vegetables, while the share for the adoption of fertilizer is approximately 13%.

Hence, the results from the two models indicate that the main pathway through which irrigation affects diet quality is through improving access to nutritious food items from own production. The importance of own production for household nutrition status is highlighted by Jones et al. (2014), Sibhatu et al. (2015), and Tesfaye and Tirivayi (2020). Even though the income generated from irrigation can serve to improve diet quality by helping farmers purchase essential food items that are not produced at home, income growth alone may not be sufficient to boost diet quality, as the translation from income to diet quality depends heavily upon a series of factors, including women's education and decision-making power (Ogutu & Qaim, 2019;

Holland & Rammohan, 2019). Furthermore, as observed by Von Braun et al. (1989), there could be cases where malnutrition could be endemic in a given society, and households may not be aware of their nutritional problems as long as they live a life comparable to most of their neighborhood. In this case, the additional income generated through irrigation use may often have little or no impact on improving diet quality, since households are less aware of their nutritional problems.

## **5. Conclusion and Recommendation**

This paper analysed the impact of irrigation use on diet quality using nationally representative data from Ethiopia. The study used the ESR model that enables us to control for both observable and unobservable heterogeneities. The results show that irrigation significantly and positively affects diet diversity. This implies that irrigation can be considered a viable instrument to enhance the diet quality and nutritional status of smallholders. Furthermore, the study also shows that irrigation encourages farmers to produce nutritionally rich crops such as vegetables and fruits and adopt productivity-enhancing technologies such as inorganic fertilizer.

The result is interesting for countries like Ethiopia, where malnutrition and micronutrient deficiencies are major public health problems. As a result, developing the agriculture sector by investing in irrigation infrastructure can contribute significantly to reducing malnourishment since the majority of poor and malnourished households rely on agriculture. Therefore, efforts should be made to tackle constraints that are impeding the adoption of irrigation technologies.

The study has the following limitations. First, since DDS is constructed based on the food consumption data collected at the household level using a 7-day recall method, the study could not account for seasonal fluctuations in food supply and intrahousehold food allocation. The consumption data of the LSLM survey were collected between February and April 2014, along with household characteristics and postharvest agriculture questionnaires. The two months fall between harvesting and the start of the next planting season. As a result, the data collection period represents an average between the food surplus season and the period when stocks are depleted. Second, DDS does not require information on quantities of foods consumed, as it relies on the list of items consumed. Last, the study also does not consider the types of irrigation technologies used by farmers.

It is worth affirming the need for further research to know more about the impacts of irrigation on diet quality and nutritional security. In particular, additional research is needed to explore the impacts of irrigation on the production and consumption of micronutrients such as zinc, iron, protein, and vitamins, as deficiencies in these micronutrients are among the major public health problems in most developing countries, including Ethiopia. In addition, the shift in farmers' decisions to produce nutritionally rich food varieties can have an implication on the type and amount of food produced and supplied to the local market. This, in turn, could affect the availability and affordability of nutritious food items for all, including landless laborers and urban dwellers. Hence, exploring the spill-over effects of irrigation on diet quality at the market level could be of interest in the literature.

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# Tables

**Table 1: Description statistics of variables used in the analysis**

Variables	Pooled (n=2,879)		Nonuser (n=2,564)	Users (n=315)	Mean Diff
	Mean	Std. Dev.	Mean	Mean	
Sex of the head	0.752	0.432	0.784	0.836	-0.052**
Age of the head	46.242	15.324	46.354	46.587	-0.233
Education HH	0.376	0.484	0.375	0.376	-0.001
Access to credit	0.198	0.401	0.216	0.241	-0.025
Livestock ownership	4.764	5.854	4.428	4.997	-0.570*
Drought index	0.027	0.163	0.031	0.006	0.024**
Distance to road	17.067	22.746	15.731	14.141	1.59
Access to market	0.470	0.499	0.492	0.333	0.159***
Land	1.245	1.386	1.226	1.400	-0.174**
Access to agri extension	0.940	0.237	0.940	0.951	-0.011
Family size	4.034	1.924	4.189	4.570	-0.381***
Wealth index	-0.925	0.964	-1.001	-0.889	-0.112**
Chemical fertilizer	0.472	0.499	0.385	0.457	-0.073**
Poor nutrient	0.036	0.187	0.021	0.025	-0.004
Slop of plots	0.784	0.412	0.791	0.841	-0.050**

Note: \*\*\* p<0.01, \*\* p<0.05, \* p<0.1

**Table 2: Estimating the impacts of irrigation using endogenous switching regression model**

Outcome variables	ATT		ATU	
	<b>coef</b>	se	<b>coef</b>	se
DDS	2.149***	0.067	0.339***	0.025

Note: \*\*\*  $p < 0.01$

**Table 3: Impact pathways: propensity score matching (PSM)**

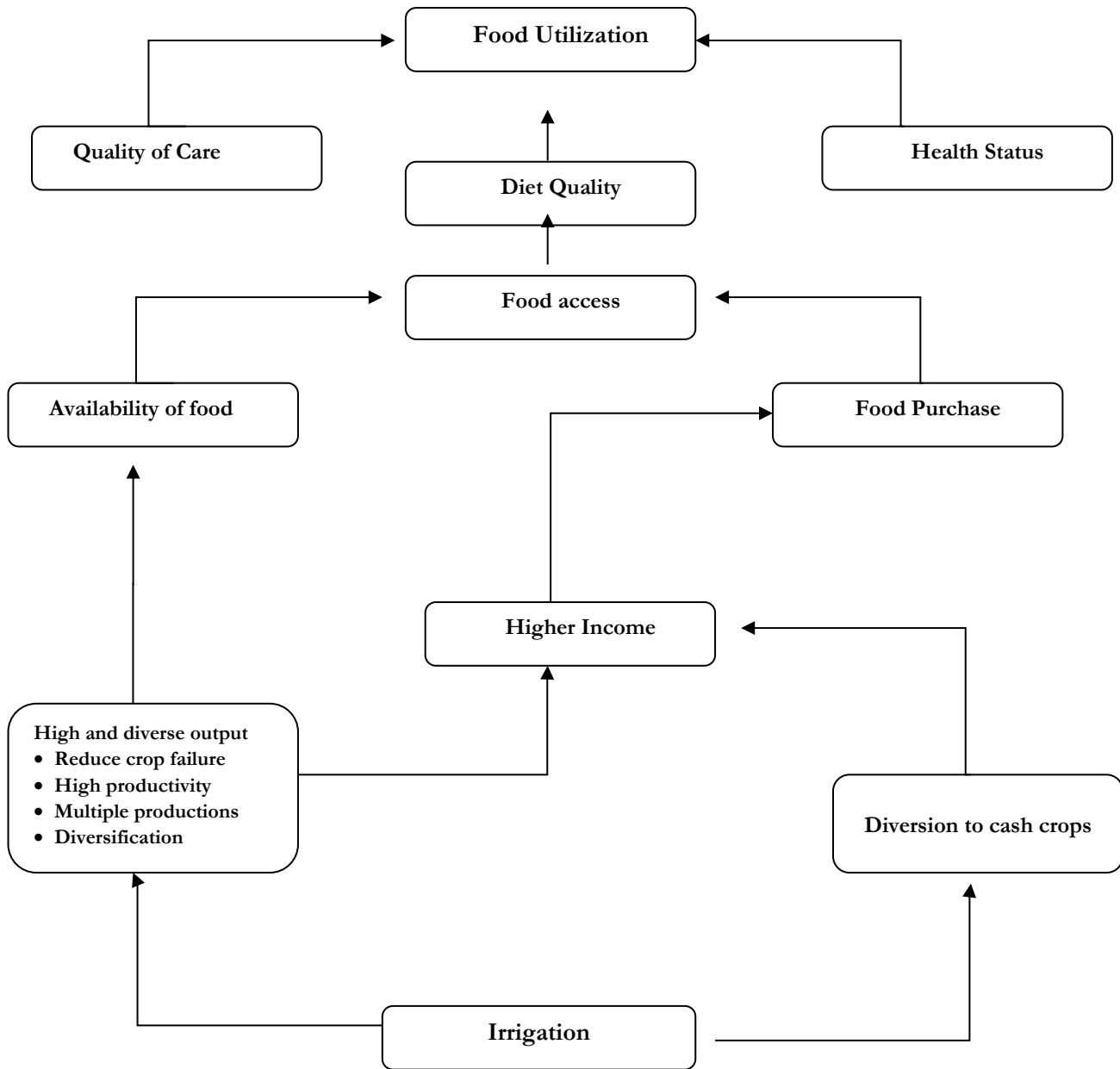
Algorithms	Produce Noncereal		Produce fruit or vegetable		Spending on nutritious food		Adoption of fertilizer		Livestock size		time for fetching water by female	
	ATT	S.E.	ATT	S.E.	ATT	S.E.	ATT	S.E.	ATT	S.E.	ATT	S.E.
Nearest Neighbor (2)	0.189***	0.026	0.266***	0.039	0.591	6.697	0.09**	0.04	0.545	0.363	0.454	1.368
Nearest Neighbor (3)	0.199***	0.024	0.292***	0.037	1.144	6.602	0.08**	0.038	0.528	0.376	1.298	0.200
Caliper matching												
Radius of 0.01	0.198***	0.018	0.295***	0.035	-2.267	6.637	0.067*	0.035	0.277	0.354	1.272	-0.120
Radius of 0.05	0.19***	0.018	0.289**	0.033	-3.214	6.493	0.067**	0.034	0.206	0.342	1.229	0.040
kernel matching												
Bandwidth of 0.01	0.199***	0.018	0.294***	0.035	-2.771	6.621	0.06*	0.035	0.275	0.353	1.267	-0.080
Bandwidth of 0.05	0.194***	0.017	0.291***	0.033	-1.372	6.429	0.07**	0.034	0.195	0.336	1.208	0.120

Note: \*\*\* p<0.01, \*\* p<0.05, \* p<0.1

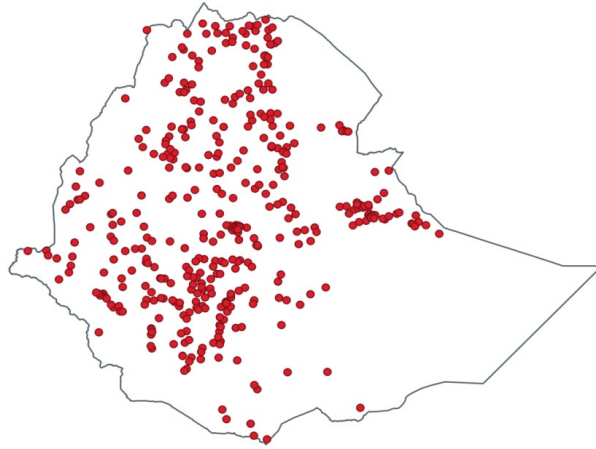
**Table 4: Impact pathways: system equations**

Mediators	Pvalue			Decision	Share
	STEP 1 (X -> M)	STEP 2 (M -> Y)	Sobel-test		
Produce Noncereal	0.000	0.004	0.026	Complete mediation	9.8
Produce fruit or vegetable	0.000	0.000	0.000	Complete mediation	44.4
Spending on nutritious items	0.352	0.000	0.352	No mediation	-
Adoption of fertilizer	0.013	0.000	0.024	Complete mediation	13.0
Livestock size (TLU)	0.072	0.000	0.087	No mediation	-
Time for fetching water by female	0.530	0.006	0.541	No mediation	-

**Figure 1: Conceptual framework of the linkages between irrigation and nutrition outcomes**



**Figure 2: Locations of the enumeration areas in the country**



# Appendix

**Table A 1: Definition and summary of variables used for this study**

Variable	Definition
Sex of the head	1 if the household head is male; 0 otherwise.
Age of the head	Number of years the household head lived
Education HH	1 if the household head can read and write; 0 otherwise.
Access to credit	1 if the household accessed credit; 0 otherwise
Livestock ownership	size of livestock owned in tropical livestock unit
Drought index	1 if village level SPEI index is less than -1; 0 otherwise
Distance to road	Distance to the nearest Major Road in km
Access to market	1 if the household leaves in the community where there is a weekly market; 0 otherwise
Land	size of cultivated land in hectare
Access to Agri extension	1 if the household leaves in the community where there is an extension worker; 0 otherwise
Family size	Number of household members in the adult equivalent
Wealth index	An index computed as the score along the first principal component of a principal component analysis applied to households' assets
Chemical fertilizer	1 if the household uses chemical fertilizer; 0 otherwise
Poor nutrient	1 if the agricultural soil nutrients availability is a severe constraint
Slop of plots	1 if at least one of the plots is flat; 0 otherwise

**Table A 2: Proportion of households that consumed each food group**

Food Group	Nonusers	Users	Mean Diff
Cereals	0.972	0.994	-0.022**
Beans	0.676	0.505	0.171***
Vegetables	0.473	0.502	-0.028
Fruits	0.203	0.257	-0.054**
Meat/poultry	0.206	0.162	0.044*
Egg	0.129	0.121	0.008
Fish	0.018	0.003	0.015*
Oil	0.802	0.838	-0.036
Dairy products	0.386	0.54	-0.154***
condiments	0.96	0.971	-0.012
Roots	0.427	0.39	0.037
Sweet/sugar	0.436	0.616	-0.180***

Note: \*\*\* p<0.01, \*\* p<0.05, \* p<0.1

**Table A 3: List of crop items produced using irrigation**

Crop	Percent	Crop	Percent	Crop	Percent	Crop	Percent
Barley	0.59	Cabbage	0.37	Ground Nuts	0.37	Coffee	6.83
Maize	12.34	Carrot	0.07	Rape Seed	0.07	Cotton	0.07
Millet	0.07	Garlic	0.81	Sesame	0.15	<i>Enset</i>	1.91
Oats	0.07	Kale	1.69	Sunflower	0.07	<i>Gesho</i>	2.28
Rice	0.07	Lettuce	0.15	Black Pepper	0.07	Sugar Cane	2.87
Sorghum	14.03	Onion	1.1	Red Pepper	0.37	Rue	0.15
<i>Teff</i>	3.31	Green Pepper	0.88	Apples	0.07	<i>Gishita</i>	0.07
Wheat	1.4	Potatoes	0.88	Bananas	4.92	Avocados	1.47
Cassava	1.1	Pumpkins	0.51	Lemons	2.87	<i>Amboshika</i>	0.29
Chick Peas	0.07	Sweet Potato	2.2	Mandarins	0.44	<i>Comtatie</i>	0.22
Haricot Beans	1.47	Tomatoes	1.76	Mangos	4.7	Other Fruits	2.57
Horse Beans	0.29	<i>Godere</i>	0.51	Beer Root	0.15	Other Spices	0.07
Oranges	2.87	Lentils	0.07	Guava	1.69	Other Pulses	0.15
Papaya	1.54	Field Peas	0.15	Spinach	0.22	Other Cereal	0.07
Citron	0.15	Cactus	0.29	Chat	13.96		

**Table A 4: The source of water used for irrigation**

The source of water used for irrigation	Percent
River	68.58
Lake	1.91
Pond	7.22
Harvested Water	1.27
Borehole	7.11
Piped water	0.96
Protected Borehole	0.21
Water Harvested	0.42
from nothing	0.21
Spring	1.06
stand piped water	0.53

**Table A 5: Falsification test for instrument**

VARIABLES	Irrigation	DDS
The slope of the plots	0.239** (0.102)	-0.051 (0.086)
Constant	-1.034** (0.459)	5.298*** (0.530)
Other controls	Yes	Yes
Observations	2,557	2,259

Robust standard errors in parentheses; note:\*\*\* p<0.01, \*\* p<0.05

**Table A 6: Maximum likelihood estimates of the endogenous switching regression model**

VARIABLES	DDS_1	DDS_0	Irrigation
Sex of the head	-0.053	0.092	0.064
	-0.247	-0.098	-0.102
Age of the head	-0.006	-0.032*	0.011
	-0.046	-0.017	-0.016
Education HH	0.670***	0.428***	-0.03
	-0.211	-0.08	-0.078
Access to credit	0.01	-0.025	-0.016
	-0.245	-0.095	-0.09
Livestock ownership	0.029	0.029***	0
	-0.02	-0.007	-0.005
Distance to road	-0.006	-0.004	0.001
	-0.004	-0.002	-0.002
Access to market	0.537**	0.047	-0.200***
	-0.234	-0.075	-0.073
Land	0.109	0.034	0.046*
	-0.084	-0.031	-0.026
Access to Agri extension	-0.061	0.167	0.309*
	-0.468	-0.16	-0.182
Family size	0.102*	0.060***	0.018
	-0.061	-0.023	-0.022
Wealth index	0.396***	0.508***	0.026
	-0.113	-0.043	-0.042
Chemical fertilizer	0.353	0.244***	0.191**
	-0.226	-0.082	-0.082
Poor nutrient	1.461**	0.029	-0.068
	-0.618	-0.222	-0.249
Drought index	-0.143	1.013***	-1.166***
	-0.667	-0.298	-0.445
Slop of plots			0.213**
			-0.102
Region dummies	Yes	Yes	Yes
sigma	0.361***	0.522***	

	-0.03	-0.036	
rho	-0.064	-0.720**	
	-0.322	-0.344	
Constant	4.420***	4.494***	-0.521
	-1.184	-0.602	-0.494

Wald test of indep. eqns.:  $\chi^2(1) = 4.46$  Prob >  $\chi^2 = 0.0348$

Robust standard errors in parentheses; note:\*\*\* p<0.01, \*\* p<0.05, \* p<0.1

**Table A 7: Sensitivity analysis for noncereals**

Gamma	sig+	sig-	t-hat+	t-hat-	CI+	CI-
1	0	0	1	1	1	1
1.25	0	0	1	1	1	1
1.5	0	0	1	1	1	1
1.75	0	0	1	1	1	1
2	0	0	1	1	1	1

Note: “gamma= log odds of differential assignment due to unobserved factors;sig+= upper bound significance level; sig- - lower bound significance level; t-hat+ - upper bound Hodges–Lehmann point estimate;t-hat- - lower bound Hodges–Lehmann point estimate; CI+ - upper bound confidence interval ( $\alpha=.95$ ); CI- - CI- - lower bound confidence interval ( $\alpha=.95$ )

**Table A 8: Sensitivity analysis for fruits and vegetables**

Gamma	sig+	sig-	t-hat+	t-hat-	CI+	CI-
1	0	0	0.5	0.5	0.5	0.5
1.25	0	0	0.5	0.5	0.5	0.5
1.5	0	0	0.5	0.5	0.5	0.5
1.75	0	0	0.5	0.5	0.5	0.5
2	0	0	-4.00E-07	0.5	-4.00E-07	0.5

See the note under Table A7.

**Table A 9: Sensitivity analysis for inorganic fertilizer**

Gamma	sig+	sig-	t-hat+	t-hat-	CI+	CI-
1	0	0	0.5	0.5	0.5	0.5
1.25	0	0	0.5	0.5	0.5	0.5
1.5	0	0	0.5	0.5	0.5	0.5
1.75	0	0	0.5	0.5	0.5	0.5
2	0	0	0.5	0.5	0.5	0.5

*See the note under Table A7.*



## Mission

To strengthen local capacity for conducting independent, rigorous inquiry into the problems facing the management of economies in sub-Saharan Africa.

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