HETEROGENEITY IN IRRIGATION TECHNOLOGY IMPACTS: IMPLICATION FOR ADOPTION

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Note: This is a preliminary version of the paper, conclusions may change as further work is done on the paper

HETEROGENEITY IN IRRIGATION TECHNOLOGY IMPACTS: IMPLICATION FOR ADOPTION

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Abstract

Agriculture remains the main pillar of Kenyan economy, a large portion of the land in the country is however arid and semi-arid (ASALs). Much of these ASALs remain underexploited leading to increased pressure on the available arable lands and natural resources e.g. wetlands and natural forests. There is, therefore, need for re-assessment of the available production techniques to try and open up some of the ASALS to production. The adoption of irrigation technologies can be one such strategy. Irrigation technology adoption still remains low among smallholder farmers in Kenya. Despite a lot of research on the impact of irrigation technology on agricultural production, there is a dearth in literature on how unobserved heterogeneity among individuals impacts on irrigation technology adoption and agricultural productivity. This study therefore aims at addressing this question by assessing how unobserved heterogeneity impacts on irrigation technology adoption and productivity among smallholder common bean producers in Kenya. Data for the study is cross-sectional household data from the 2014 Tegemeo institute/ MSU rural household baseline survey on 7000 households in Kenya. Instrumental variable (2SLS) technique was used to analyze the impact of technology adoption on agricultural productivity to account for potential endogeneity in selecting the technologies. The 2SLS results were compared to those of a correlated random coefficient model of yields to assess the implication of the differences between homogeneity and heterogeneity assumptions among smallholder common bean producers in Kenya. The study found evidence that adoption of irrigation technology strongly depended on unobserved heterogeneity. It is thus important for policy makers and other stakeholders to consider

this unobserved heterogeneity when designing intervention programs to ensure the target audience is the right one and also be able to differentiate the technology components accordingly.

Introduction

Over half a billion smallholder farmers produce most of the food consumed in developing countries. They farm over 80% of the land in Asia and Africa. Their productivity however still remains below the world average. Increasing agricultural productivity in developing countries will thus greatly help in strengthening the resilience of food markets, enhancing food security systems and promoting sustainability of smallholder agriculture (Nelson et al., 2012)

Despite agriculture being a significant contributor to the Kenyan economy, most of the land is categorized as Arid and Semi-Arid (ASALs) (Government of Kenya, 2007). Most of these lands have the potential for irrigation if necessary investments are undertaken. Opening up these lands to agriculture could improve agricultural performance in the country as well as promote food security. The population of Kenya has also been increasing since the 1960s when the country attained its independence. The same has been agricultural production which has been growing relatively faster than the population on average. This growth in agricultural production has partly been sustained through growth in area under production, however from 2010, as the area under production increased, the yield has been declining (Dietz *et al.,* 2014). This is presented in Figure 1. This might be attributed to the expanding of agricultural production to marginal lands. Over the past years, agriculture has been expanding towards marginal lands and water catchment areas. The Mau Forest complex, a major water catchment area has witnessed considerable changes in Land use and land cover (Masese *et al.*, 2012). Agricultural activity increased by 203% in the Mara River basin between 1973 and 2000 (Mati *et al.*, 2008)

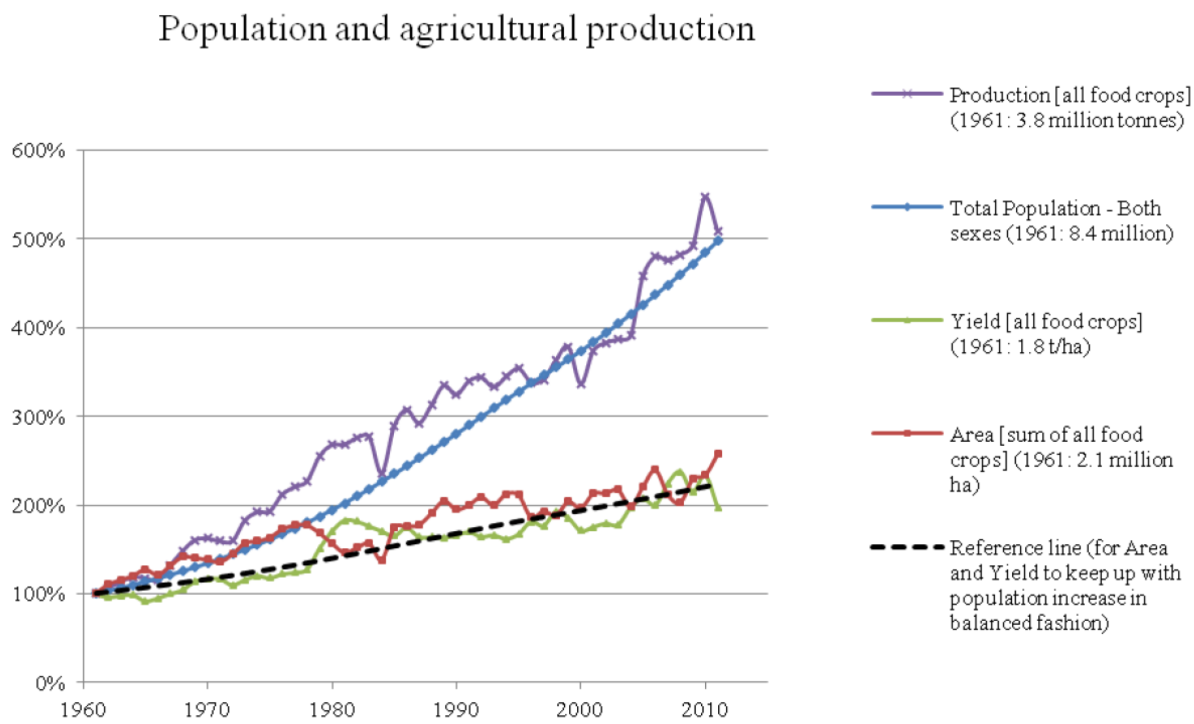

Figure 1: Kenya 1961-2010: population and food crop growth indexes

Source: FAOSTAT data in (Dietz *et al.*, 2014)

With these facts in mind, it is necessary to understand the alternative strategies in which agriculture as a contributor to food security can be improved without exerting much pressure on the scarce resources like land and water. One alternative to achieve this is through the adoption of modern and efficient technologies.

Agricultural technologies can be a potential means for increasing smallholder agricultural productivity and production, improving household food security and raising farmer's income (Mutenje *et al.*, 2016). Active engagement of local communities as well as investment in infrastructure and technologies to improve agricultural productivity can contribute towards long-term development of agriculture in Sub Saharan Africa (Grindle *et al.*, 2015). With 17% of the land in Kenya categorized as medium to high potential for irrigation, less than 10% is utilized for the same. This amounts to only 2% of the total arable land in Kenya (FAO, 2015). Improving and expanding irrigation technology can help increase agricultural productivity hence reduce the gap between the growing population and food production.

The Government of Kenya recognizes the role of irrigation development as a drought mitigation measure. Numerous initiatives have been undertaken by the government, the private sector and the donor community towards irrigation development since the 1970s. It was estimated that by 2010, about 120,000 ha were under irrigation with 47% (54,800ha) falling under smallholder community-based irrigation schemes, 41% (49,000 ha) and 13% (16,000 ha) being privately run irrigation schemes and National Irrigation schemes respectively (Kenya engineer, 2016).

Factors influencing irrigation technology adoption

Irrigation technology has been viewed as the missing link between the current state of Agriculture in Sub Saharan Africa and its transition to a developed state. There still exists a significant opportunity to expand the region's irrigation potential (Hua Xie *et.al.*, 2014). This will help in increasing agricultural production necessary for economic development and improved food security. There is also need to link agriculture to water management and education systems, which are mostly executed separately, in order to realize real agricultural development and poverty reduction outcomes in developing countries. Adequate investment in agricultural water management and rural infrastructure, accompanied by formulation of appropriate policies, may be the means to break from the vicious cycle of poverty affecting many smallholder African farmers (Hanjra *et. al.*, 2009)

Promotion of smallholder irrigation can be a good strategy for enhancing income generation and food security among Sub Saharan Africa poor smallholders. To be successful, the technology should lead to increased consumption, asset accumulation and reduced persistent poverty among the adopters. In the long run, it should lead to institutional feedbacks that support sustained economic development and nutritional improvements (Burney & Naylor, 2012). Asset availability, household incomes, institutional performance and innovation by smallholder farmers influence smallholder farmers' irrigation adoption decisions (Muzari, Gatsi, & Muvhunzi, 2012). Labour availability and increase in the number of extension visits affect the probability of irrigation technology adoption too (Adeoti, 2009).

Kenya, being predominantly arid and Semi-arid and its agriculture dominated by smallholder farming, requires special attention in terms of irrigation technology. Conventional large-scale irrigation should be accompanied by the development of micro-irrigation technologies that will serve a large section of the country. Micro-irrigation technologies result in a significant productivity and economic gains among the smallholders. Important determinants of micro-irrigation technology adoption include access rights to groundwater use, cropping patterns, cash availability, education level and social/ poverty status of the farmers (Namara, Nagar, & Upadhyay, 2007).

Effect of irrigation technology adoption on agricultural productivity

Transforming smallholder agriculture in Sub-Saharan Africa requires a shift from the current rain-fed subsistence systems to more commercial, highly productive agricultural systems. This can be used as part of poverty reduction strategies in smallholder farming communities. Regions with the best poverty-reduction performances also happen to have greater proportions of irrigated land (Lipton *et al.,* 2003). Potential benefits of irrigation include increased yield, higher and more stable outputs, lower consumer prices and greater demand for labour arising due to the adoption of irrigation. Irrigation agriculture increases smallholder welfare through improving agricultural productivity, increasing employment rates and incomes for irrigating farm households as well as creating opportunities for diversification of rural livelihoods (Mangisoni, 2008; Smith, 2004).

Irrigation impacts different categories of target beneficiaries differently. The impacts vary depending on the technology itself, position along the distribution system (head enders or tail enders), institutional rules governing access to water and its use, maintenance systems and synergies with other agricultural inputs (access to land, credit, seeds, fertilizer etc.). The poor are mostly a heterogeneous group with different socio-economic, geographic and other characteristics, irrigation technologies thus impact them differently. Smallholder farmers may be impacted through increased yields and incomes, landless labourers through increased demand for agricultural workers and the urban poor through reduced average food prices and also reduction in rural-urban migration (Lipton, Litchfield, & Faures, 2003). It is thus important to combine the different aspects of an irrigation system so as to achieve the intended benefits to the farmers. Cheap technologies may not always be the best for poor farmers, especially in Sub-Saharan Africa. Risks like high transport costs, repair/ replacement costs, and unpredictable energy supplies favour higher costs, longer lifetime and stable products. Technologies that facilitate only minimal efficiency gains may result in dis-adoption later due to inadequate economic returns during the initial learning period. If saving on upfront costs comes at the expense of exclusion of one of the other important components of the irrigation technology, the tradeoff might not be favourable to the targeted beneficiaries in the long run (Burney & Naylor, 2012; Kulecho & Weatherhead, 2005).

The successes associated with irrigation farming varies widely across different regions. Water resources management decisions should recognize this and therefore be based on a holistic and livelihood centred assessment of irrigation benefits and costs that goes beyond the food production objectives (Smith, 2004)

Irrigation technology benefits the poor mainly through improved production, increased productivity, substantive reduction in crop failure risks and higher returns all year-round, from both farm and non-farm employment. Smallholders' can adopt diversified cropping patterns and also switch from low-value subsistence to high-value market-based production. This increase in production and productivity leads to food availability and affordability to the vulnerable and mostly poor net food buyers. (Hussain & Hanjra, 2004)

Common bean production in Kenya

Kenya is the 7th largest global producer of common beans and ranks 2nd in East Africa after Tanzania. The crop is the most important pulse in the country while it comes second after maize as a staple crop. Common bean is grown by more than 1.5 million smallholder farmers in Kenya, with yields averaging at about 0.6 MT/ hectare. The leading production areas are the Rift Valley region, Eastern, Nyanza, Western and Central Kenya. Average national consumption stands at 755,000 MT per year while production is at 600,000 MT/ year. The average consumption per capita is 14 kg/ year, this may rise to as high as 66 kg/ year in Western parts of the country. Deficits in consumption are usually filled by importing from neighbouring countries like Ethiopia, Tanzania and Uganda (Nzuma, 2016).

Drought is by far the main common bean production constrains in the country with an occurrence probability as high as 60% in Eastern parts of Kenya. All varieties of beans experience severe declines in yields as a result of these recurrent droughts (Katungi, *et al*., 2010).

Comparison of common bean production in East Africa (2009 – 2014)

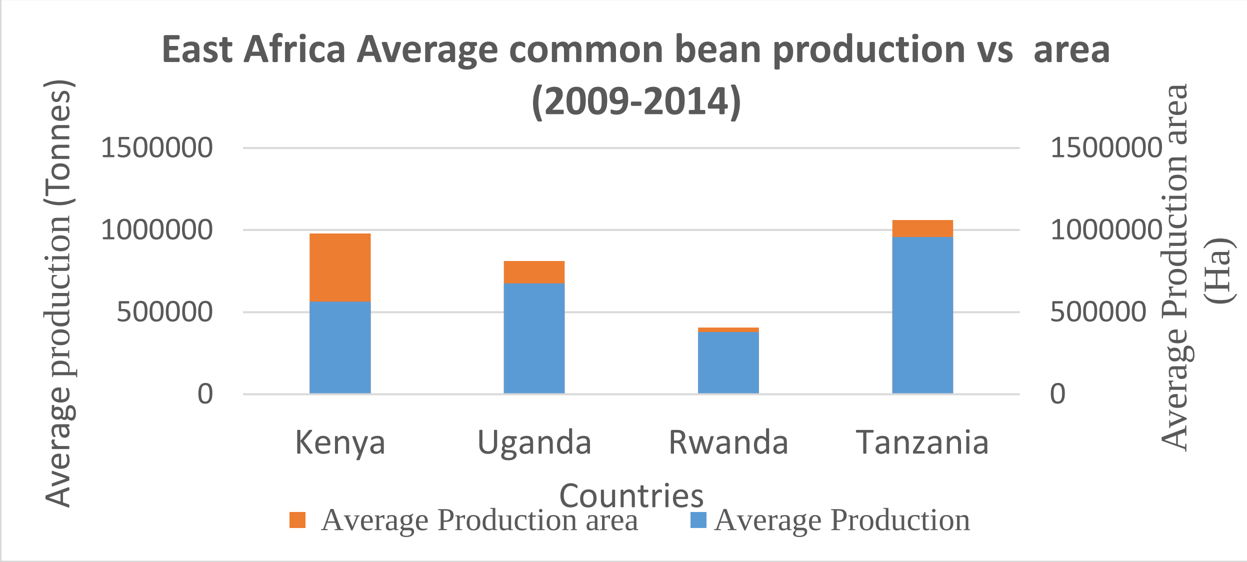

Figure 2: Comparison of common bean production in East Africa (2009 – 2014)

Source: (FAOSTAT, 2017)

The graph in figure 2 compares the total common bean production in East African versus the land area used in production between 2009 and 2014. The ratio of land used to production was highest in Kenya as compared to the other countries. This means that the country was producing less efficiently as compared to other countries analyzed. In Figure 3, Average common bean yields from 2009 to 2014 were compared between Kenya, Uganda, Rwanda and Tanzania. The results showed that Kenya had the least yield among the 4 countries at slightly less than 6000 Hg/ Ha, the other countries had a yield greater than 8000 Hg/ Ha. It is, therefore, necessary to understand why this disparity exists and any potential improvement strategies

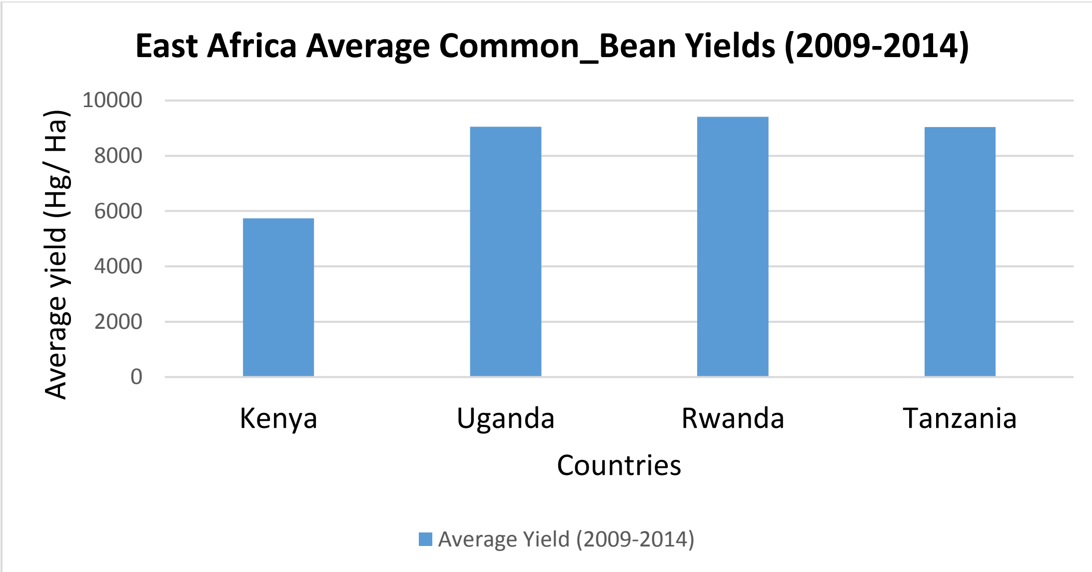

Figure 3: East Africa Common Bean Production vs yields

Source: (FAOSTAT, 2017)

Methodology

Technology adoption is expected to be endogenous to common bean yield since smallholder farmers choose whether to adopt the irrigation technology or not. The effect of irrigation technology adoption on common bean yield may also be affected by other unobservable characteristics not exclusively captured in the survey. This issues thus limit the ability of the OLS to be consistent. The IV approach offers an alternative approach for estimating the parameters in models with endogenous regressors and errors-in-variables models. Changes in the instrument are associated with changes in the explanatory variable (endogenous in this case) but do not lead to changes in the dependent variable except directly through the explanatory variables. The IV estimator $\hat{\beta}_{iv}$ is consistent for β provided that the instrument z is uncorrelated with the error μ and correlated with the regressor x.

Model setup

We consider a regression model with a scalar dependent variable, y_1 (Common bean yield per acre), one endogenous regressor, y_2 (irrigation technology adoption choice) and k_1 exogenous regressors (inclusive of the intercept) denoted by x_1. This can be set up as:

$$y_{1i} = y_{2i}\beta_1 + x'_{1i}\beta_2 + \mu_i, i = 1, \dots . N \quad (1)$$

The regression errors μ_i are assumed to be uncorrelated with x_{1i} but correlated with y_{2i}. This correlation makes the OLS estimator inconsistent for β. To obtain a consistent estimator, we assume the existence of at list 1 IV (Just identified case for a single endogenous variable) x_2 for y_2 that satisfies the assumption that $E(u_i|x_{2i}) = 0$. The instrument x_2 needs to be correlated with y_2 so as to provide some information on the endogenous variable.

This model can thus be written as $y_i = x'_i\beta + \mu_i$

Where the regressor vector $x'_i = [y_{2i}\, x'_{1i}]$ combines both the endogenous and exogenous variables. The dependent variable is denoted by y rather than y_1. The vector of instruments is denoted as $z'_i = [x'_{1i}\, x'_{2i}]$ where x_1 serves as the ideal instrument for itself and x_2 is the instrument for y_2. The instruments, z satisfy the conditional moment restriction

$$E(u_i|z_i) = 0 \quad (2)$$

We, therefore regress y on x using instruments z (Cameron & Trivedi, 2010). Finally, the effect of irrigation technology adoption on smallholder common bean productivity is allowed to vary with unobservables. We assume that the benefits of adopting the technology varies across individuals in a manner that cannot be fully observed. By allowing random coefficients to correlate with explanatory variables, a Correlated Random Coefficient (CRC) model is obtained. This allows for heterogeneous effects combined with endogeneity to be incorporated into the analysis

(Wooldridge, 2014). The CRC model will thus be used to analyze how heterogeneity among individuals affects irrigation technology adoption and smallholder common bean productivity in Kenya. Since the watering system (endogenous variable) is binary, the control function (CF) approach was used where a probit model was used in the first stage of the regression and OLS in the second stage. The 2 equations were specified as

$$y_2 = 1[z\delta_2 + v_2 > 0] \quad (3)$$

$$y_1 = z_1\delta_1 + \gamma_1 y_2 + \mu_1 \quad (4)$$

Where $1[.]$ is the binary indicator function of the First stage. We assumed that $(\mu_1 v_2)$ is independent of z and that

$$v_2 \sim Normal\ (0,1) \quad (5)$$

y_2 follows a Probit model where

$$P(y_2 = 1|z) = \Phi(z\delta_2) \quad (6)$$

$\Phi(.)$ represents the standard normal Cumulative Distribution Function (CDF)

The first stage regression is specified as:

$$y_{i2} = z_i\pi_2 + v_{i2}, E(v_{i2}|z_i) = 0 \quad (7)$$

The generalized residuals can then be obtained from the probit model by

$$\hat{r}_{I2} \equiv y_{I2}\lambda(z_i\hat{\delta}_2) - (1 - y_{i2})\lambda(-z_i\hat{\delta}_2), i = 1,..N \quad (8)$$

Where $\lambda(.) = \frac{\phi(.)}{\Phi(.)}$ is the Inverse Mills Ratio (IMR)

Finally, the control function was estimated by regressing y_{i1} on $Z_{i1}, y_{i2}, \hat{r}_{I2}$

All the unobservables were assumed to be independent of z_i. The estimating equation for the CRC model thus is

$$E(y_{i1}|z_i, y_{i2}) = E(y_{i1}|z_{i1}, y_{i2}, v_{i2}) = z_{i1}\delta_1 + \gamma_1 y_{i2} + \eta_i v_{i2} + \beta_1 v_{i2} y_{i2} \qquad (9)$$

As used in (Wooldridge, 2014)

The variables used in the model are described in Table 1 below

Table 1: Description of variables used in the model

VARIABLES	Description	Measurement	Expected sign
	Dependent Variable		
Bean_yield	Common bean yield per acre	Kgs	
	Independent Variables		
Watering system	The watering system used in the field	1 = irrigated 0 = rainfed	+
Output Price			
Extension Distance	Distance to extension service	Kms	-
Household size	Household size	Number	+/-
Age	Age of household head	Years	+/-
Gender	Gender of household head	0 = female 1 = male	+/-
Education	Education level of household head	Years	+
Irrigation distance	Distance to permanent irrigation water source	Kms	-
Irrigation water	Access to irrigation water	0 = No 1 = Yes	+
Agricultural group	Member of an agricultural group	0 = No 1 = Yes	+
DAP Price	Price of DAP fertilizer per Kg	KES	-
CAN Price	Price of CAN fertilizer per Kg	KES	-
Seed Cost	Cost of common beans seed per Kg	KES	-
Pesticide Cost	Pesticide cost per Litre	KES	-
Fungicide Cost	Fungicide cost per Kg	KES	-
Gunny bags price	Cost of 1 piece gunny bag	KES	-
Daily Wage	Average daily wage	KES	-
WS*genger	Watering system*gender		+/-
	Interaction Variables		
WS* ExtDist	Watering system*Extension Distance		+/-
WS*Household size	Watering system*Household size		+/-
WS*age	Watering system*age		+/-
WS*education	Watering system*education		+/-
WS*Daily wage	Watering system* Daily wage		+/-
Gen residuals	Generalized residuals		+/-
WS*GenRes	Watering system*Generalized residuals		+/-

Results and discussion

Descriptive analysis was done and the results presented in Table 2

Table 2: Summary statistics

Variable	Mean	Std Dev
Bean_yield	111.66	143.42
Output Price	55.46	10.13
DAP Price	74.96	4.18
CAN Price	58.63	6.36
Seed Cost	49.26	41.41
Pesticide Cost	956.31	190.31
Gunny bags price	48.88	7.19
Household size	5.58	2.47
Age	50.11	14.87
Education	7.93	3.62
Extension Distance	4.40	1.35
Irrigation distance	5.55	3.25

Effect of Irrigation Technology adoption on smallholder common bean productivity, Kenya

To analyze the effect of irrigation technology adoption on smallholder common bean productivity, homogeneity versus heterogeneity assumption, three models were used. These were the 2 stage least squares (2SLS), The Control function method (CF) and the Correlated Random Coefficient model (CRC). The results of all the 3 models were pretty robust with the directions of the impacts being similar, differences were only observed in the magnitude, which were not ridiculously different from each other. The results are as presented in Table 3. Irrigation technology increased bean yield per acre by 577, 331 and 206.5 Kgs per acre under the 2SLS, CF and CRC models respectively. All the effects were significant at 1% level. Output price was also significant at 1% level in all the 3 categories. A KES 1 increase in output price increased the yield by 0.92, 0.82 and 0.84 Kgs per acre under the 2SLS, CF and CRC model respectively. The cost of seed per Kg was negative and statistically significant at 5% under the 2SLS and at 1% level under CF and CRC models respectively. Increase in seed cost per Kg reduced the yield per acre by 0.14, 0.153

and 0.142 under 2SLS, CF and CRC respectively. The price of gunny bags used for storing maize was also negative and significant at 5% in all the 3 categories. Increase in the price of gunny bags by KES 1 reduced the yield by 0.971, 0.788 and 0.859 under 2SLS, CF and CRC models respectively. Household size was positive and significant at 1% level across all the 3 categories. Increase in household size by 1 member increased the yield per acre by 3.85, 3.66 and 3 Kgs for the 2SLS, CF and CRC models respectively. This may be attributed to beans being a labor intensive commodity, thus the larger the household, the larger the chance of more labor especially in cases of imperfect or missing labor markets. Education positively influenced the bean yield per acre with 1 year increase in education increasing yield per acre by 1.08, 1.04 and 1.12 Kgs in the 2SLS, CF and CRC models respectively. Distance to extension services was also significant at 1% in all the 3 categories. An increase in distance to extension services by 1 Km reduced the bean yield by 37, 45 and 46 Kgs under the 2SLS, CF and CRC models respectively. Finally, gender was significant at 5% and 10% significance level under the 2SLS and CF approaches respectively. Female headed households produced more per acre by 10.92 and 7.58 Kgs under the 2SLS and CF approaches as compared to their male headed counterparts. This may be probably because beans is regarded as a woman's enterprise mostly used for food crop. The watering system used was also interacted with other variables to assess the potential of unobserved heterogeneity among individuals and its effect on irrigation technology adoption and productivity. The explanatory variables used in the interactions were centered on the sample means in order for the coefficient on the endogenous variable to capture the average effects on the dependent variable (Wooldridge, 2014).

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Table 3: The effect of irrigation technology adoption on smallholder common bean productivity, Kenya

	(1)		(2)		(3)	
Models	**2SLS**		**CF**		**CRC**	
Dependent variable			**Bean_yield**			
Explanatoty Variables						
Watering system	577.1***	(105.90)	331.0***	(42.27)	206.5***	(35.98)
Output Price	0.920***	(0.32)	0.821***	(0.24)	0.844***	(0.24)
DAP Price	1.222	(0.81)	1.004	(0.67)	1.016	(0.67)
CAN Price	-0.0926	(0.37)	-0.259	(0.34)	-0.440	(0.34)
Seed Cost	-0.140**	(0.06)	-0.153***	(0.05)	-0.142***	(0.05)
Pesticide Cost	0.00357	(0.01)	0.0129	(0.01)	0.0144	(0.01)
Gunny bags price	-0.971**	(0.49)	-0.788**	(0.38)	-0.859**	(0.38)
Household size	3.850***	(1.31)	3.661***	(1.02)	3.017***	(1.01)
Age	-0.0440	(0.17)	-0.105	(0.13)	-0.170	(0.13)
Education	1.081*	(0.63)	1.044*	(0.56)	1.120**	(0.57)
Extension Distance	-37.09***	(1.86)	-45.17***	(1.79)	-46.37***	(1.80)
Agricultural group	5.554	(10.98)	11.10	(8.92)	11.38	(9.05)
Gender	-10.92**	(5.16)	-7.576*	(4.51)	-4.782	(4.43)
WS*genger	68.45	(245.30)	-13.24	(70.43)	-29.18	(71.30)
WS* ExtDist	-161.1***	(38.58)	-47.37***	(12.55)	-53.49***	(12.95)
WS* Household size	5.073	(27.79)	9.301	(7.77)	15.86*	(8.23)
WS* age	-3.183	(7.14)	0.509	(1.70)	0.394	(1.77)
WS* Education	7.767	(20.93)	10.41	(6.42)	12.32*	(6.68)
WS* Daily Wage	-4.060***	(0.90)	-0.937***	(0.34)	-0.758**	(0.34)
Gen residuals			-129.5***	(16.54)	54.07***	(19.22)
WS*GenRes					-82.06***	(19.97)
Constant	146.9***	(50.52)	205.6***	(40.80)	230.9***	(41.18)
Observations	**5,121**		**5,121**		**5,121**	
R-squared	**0.005**		**0.399**		**0.390**	

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

The interaction between the watering system and extension distance was negative and significant at 1% level across all the 3 categories. Using irrigation water but increasing distance to extension by 1 km reduced yield per acre by 161, 47 and 53 Kgs respectively under the 2SLS, CF and CRC models respectively. This may serve to show the importance of extension when it comes to effectiveness of irrigation technology among smallholder farmers in Kenya. Ensuring farmers can access irrigation technology and also extension services can be a means to improve smallholder common bean productivity in the region. The interaction between the Watering system and daily wages was also negative and significant at 1% level for the 2SLS and CF approach while significant at 5% level under the CRC model. Increase in daily wages by KES 1 while using irrigation water reduced the bean yield by 4.06, 0.94 and 0.76 Kgs per acre under the 2SLS, CF and CRC models respectively. Increase in daily wages reduced the productivity per acre probably because common beans are a labor intensive commodity coupled with the labor for laying out the irrigation infrastructure

The correlated Random Coefficient model accounts for the randomness that may be present in watering system. The Generalized residual term (Gen residuals) and the interaction between the watering system and the generalized residual (WS*GenRes) were jointly significant at 1% level with an F-value of 16.20. This serves as evidence that the treatment effect of using irrigation technology depends strongly on unobserved heterogeneity of individuals. The difference between the CRC and the 2SLS approach on the effect of irrigation technology adoption on smallholder common bean productivity could be explained by the fact that 2SLS assumes homogeneity in the distribution of benefits. The 2SLS estimate is thus the average treatment effect for the farmers who choose to use irrigation technology because they have access to irrigation water and the distance to irrigation water. This might be very different from the overall population especially considering the effect of the random component of the individuals. Using irrigation water thus improves common bean yield per acre by 206.5 Kgs under the CRC as compared to 577 Kgs under the 2SLS approach.

Conclusion

It is thus important to consider the unobserved heterogeneity of individuals when analyzing the impact of a certain project/ program to stakeholders. The analyst should be cognizant of the fact that though the effect of a project/ program is positive, it may impact on different groups of farmers differently, it is thus important to consider this subtle differences among the beneficiaries of a project/ program to ensure its success

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