Synergistic Green and White Revolution: Evidence from Kenya and Uganda

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Summary

Rising agricultural productivity in developing countries is crucial to ease the tension of increased population and haunting concern on food security. Nevertheless the soaring price of fertilizer and sluggish dissemination of improved seed varieties prohibit the poor to tap benefits from increased productivity. In the presence of the pressing button on food security, subsidizing fertilizer and seeds is recently voiced heavily. This study reveals that the adoption of improved maize variety in Kenya leads to higher yield than that in Uganda. By introducing livestock programs, the agricultural productivity in Kenya is sustained with a synergy between the "Green Revolution" and "White Revolution". To tap agricultural potentials in Africa, subsidizing fertilizer is not sufficient; there exists multiple trajectories to achieve in food security, agricultural transformation and environmental sustainability.

Keywords: green revolution, livestock, fertilizer, food security, propensity score matching, Africa

JEL: Q12, Q18, Q56

1 Introduction

Increased population and speeding urbanization challenge developing countries. The decreased farm size prohibits smallholder farmers' access to agricultural technology, market information and public services, and even leads to further environmental degradation (Lee & Barrett, 2001; Pender, Jagger, Nkonya, & Sserunkuuma, 2001). Increased productivity therefore contributes to not only food security and poverty reduction, but also environmental sustainability. Over the past decades, productivity of food grains in South Asia has experienced extraordinary increase, which was attributed to widespread adoption of new varieties (in particular rice and wheat), intensified use of fertilizer and improved irrigation system. The first flush of the Green Revolution in the 1960s and 1970s features such a rapid increase in cereal production, playing overarching role to avoid predicted massive food shortages. In Africa, however, the Green Revolution has not had such a sustained success (Evenson & Gollin, 2003; Otsuka & Kalirajan, 2005).

Agriculture indeed stands as a central key in many Sub-Saharan economies. For example, 80 percent of Uganda's labor is employed in agriculture, which contributes to half of the nation's GDP (Sserunkuuma, 2005). In recognizing the importance and unfilled potential in agricultural sector, many formerly central-planned economies in Sub-Saharan Africa embarked on structural adjustment programs with objectives to liberalize input and output markets. The experience of liberalization, however, has been unequivocally mixed as it leads to stagnation and volatility. [2]

The grain yield has been stagnant in Sub-Saharan Africa (Otsuka & Kalirajan, 2005). The anemic national agricultural research system (NARS) in many Sub-Saharan African countries retards the dissemination of high-yield seed varieties. Moreover, to tap yield potential, the adoption of improved seeds should be complemented with responsive fertilizer. Nevertheless, the soaring fertilizer prices, driven by oil price and exacerbated by poor local infrastructure, further depress agricultural productivity. As the lack of access to fertilizer leads to shifting cultivation and causes more land degradation and deforestation, subsidized fertilizer

[2] Uganda is such a case where the lack of institutional framework shackles and undermines the liberalization (Reinikka & Collier, 2001).

programs are voiced heavily by international donors. The favorable bountiful fertilizer programs (for example in Malawi), however, are so costly to maintain sustainably, although they lead to a bumping regional harvest in 2007 (Economist, 2008). Questions arise: Is lack of fertilizer application the overarching determinant for the sluggish yield? How is the adoption of improved varieties responded by other inputs? How do policymakers in Sub-Saharan Africa sequence reforms to achieve in transformation by increasing sustainable agricultural productivity? This study attempts to answer these questions.

In this study, after reviewing and formalizing related theories, propensity score matching (PSM) is employed to mitigate the endogeneity problem, specification and heterogeneity of populations in Uganda and Kenya. Furthermore, bio-physical condition in these two countries is controlled by using GIS data. This study reveals that the treatment effect of adopting improved varieties on maize yield in Kenya is higher than that in Uganda. The adoption of improved varieties encourages more fertilizer and manure use in Kenya because of the fertilizer credit program, policy-induced livestock program and favorable institutional environment.

2 Review of Theories

2.1 Green Revolution and White Revolution in Sub-Sahara

To ensure the needed investment in the natural resource base under high population growth and to strengthen local and national food security in Africa, a food-based growth strategy is critical (Lynam & Blackie, 1994). Such a strategy recognizes the dominant role that the food staple plays in the early phases of structural transformation. Maize, one of the few crops that can be planted in both temperate regions and in tropical and sub-tropical regions, was advanced as a major part of Green Revolution breeding. [3] But the development of “heterosis” breeding methods – firstly for maize varieties – was sluggish in Africa until independence from colonial

[3] In Sub-Saharan Africa, high potential “Green Revolution” crops such as wheat, rice and maize are not chosen over roots and tubers (e.g. cassava, potatoes and yams) because they are susceptible to lack of rainfall at critical times in the growing season. However, the cultivation of roots and tubers leads to rapid soil mining, challenging sustainable intensification (Dorward, Kydd, & Poulton, 2006).

regimes. [4] Kenya, however, is an exception in Africa (Evenson & Gollin, 2007).[5] Driven mainly by large commercial farms, Kenya witnessed a success story of the maize Green Revolution in the 1970s (Hassan, 1998). As one of the few countries introducing and developing early "heterosis" breeding methods, Kenya made a big progress in increasing its agricultural productivity, although the yield started to stagnated due to the heavy state involvement that impeded the efficiency of input and output markets. Rather than following a full liberalization as in other Sub-Saharan countries, Kenyan government gradually diversified its national agricultural research system and induced integrated agricultural development strategy by replacing local cows with cross-breeds between local and European cows, staging a "While Revolution".

Neighbored with Kenya, Uganda made a big progress in transition to market economies, but markets – particularly agricultural markets – are subject to high transaction costs and insufficient public services. Although a number of productivity-enhancing technologies have been developed and released, its national agricultural research system (NARS) is relatively underdeveloped.

2.2 Review of Theories

To tap agricultural potential of improved seed varieties, yield-enhancing fertilizer, appropriate land management practices, and appropriate institutional support for developing and disseminating these technologies are all crucial. A variety of hypotheses – some of them complement with each other while some are conflicting – explain households' use of green revolution technologies and appropriate farming practices. Hereinbelow I briefly summarize the related theories to support the empirical analysis that is given in the next section.

The first school of thought argues that high rate of population growth leads to pressure on demand for food, yield-enhancing varieties, and agricultural

[4] "Heterosis" is often used to create "hybrid" varieties. Hererosis hybrids carry a productivity advantages by enhancing the two inbred parent lines in the first-generation progenies.

[5] The Kenya Agricultural Research Institute (KARI), a public research institute developing new maize varieties, releases mainly open pollinated varieties (OPVs). Meanwhile, the Kenya Seed Company (KSC), a private but state-umbrellaed company, releases new maize varieties including both OPVs and hybrids. A thorough description of Kenyan agricultural system was reviewed by Groote et al. (2005).

intensification. The population pressure affects not only the incentive of adopting modern technologies, but also changes the composition and structure of an economy (Boserup, 1975; Salehi-Isfahani, 1988, 1993). For lagging areas without established physical and economic infrastructure, the obtained wage income from migration is usually a substitution for limited agricultural revenues. Meanwhile, agricultural productivity may decline as a result of the accelerated of migration. The labor migration as an alternative to sales of agricultural surplus appears in both sparsely populated and densely populated areas (Boserup, 1975). Boserup further argues that, in developing countries, the surplus of agricultural labor is hardly additive to subsistence sector in countries where economic development and rising real incomes in urban sector emerge. [6]

The second school of thought on farmers' adopting agricultural technology highlights risk aversion and human capital. Innovative agricultural technologies may expand the amount of risk associated with farming and lead to volatility, at least being expected by smallholders. As a result, farmers allocate only part of their land to high yield variety (HYV) while continuing to allocate land to traditional technologies (Sunding & Zilberman, 2001). For example, Benin et al. (2004) find that, to manage risks, farmers in the highlands of Ethiopia adopt traditional varieties that are generically diverse. Such a risk-aversion hypothesis associated with innovation and the prevalence of risk aversion among farmers was finely examined and verified by Feder and O'Mara (1981). They conclude that risk aversion may be explained as a deterrent to innovation adoption for small farmers only to the extent that adoption entails fixed costs. "Such fixed costs are not a characteristic of the HYV technology itself, but are a result of information-acquisition requirements, inefficient input distribution systems, and credit facilities burdened with red tape" (Feder & O'Mara, 1981, p. 73).

Uncertainties are expected to decrease over time as farmers become more knowledgeable about the innovation's characteristics (Feder, 1980). The impact of risk aversion on the adoption of Green Revolution technology can be mitigated by

6 But improved infrastructure reduces transaction costs and accordingly increases farm surplus that might outnumbers incomes from migration. As such, investments in rural infrastructure promote agricultural growth, reduce migrating pressure on urban areas, and contribute to poverty reduction (Fan, Zhang, & Zhang, 2004).

enhancing human capital. Foster and Rosenzweig (1996) find that technical change is likely to have a greater effect on profits in an educated population than in an uneducated one. More educated farmers are assumed to be earlier adopters, because they may have better access to information and may be able to apply innovations more efficiently (Lin, 1991). As such, the initial levels and distribution of human capital matter for the subsequent rates of economic growth propelled by technical change, and thus matter for the resulting income distribution.

The third school of existing theories explains the capability of taping agricultural potential for a perspective of community level, and observes the interaction between individuals and resident communities, thus going beyond the individual level. Such a "network hypothesis" can be backdated to a "geographic consideration", which was reviewed by Sunding and Zilberman (2001). Geography sets two barriers to adoption and its outcome: climatic variability and distance. Distance is claimed as a dominant obstacle for adoption, and producers in locations farther away from a regional center are likely to adopt technology later. It is however a greater challenge to adopt technologies across different latitudes and varying ecological conditions, although improved infrastructure and communication technologies are helpful.

Geographic explanation of adoption is not telling as it is interacted with many of unobserved (or observed but intertwined) factors. Recent studies increasingly emphasized the role of networks in the adoption decision and diffusion (Chantarat & Barrett, 2007). For example, it is found that farmers do not learn from others in the villages, but rather rely on individual networks that are not necessarily based on geographic closeness, for example, ethnic clan and gender lines (Bandiera & Rasul, 2006; Conley & Udry, 2001). Matuschke (2007) find that, while endogenous networks play a more significant impact on adoption, exogenous network effects became stronger in later stages of diffusion. [7] Her study verifies and complements

[7] Matuschke (2007) concluded that village level networks are an appropriate proxy for network effects *only* when considering widely diffused technologies. In early diffusion stages, they may underestimate the effect that networks may have on adoption.

with the findings of Bandiera & Rasul (2006) whose study shows social effects are positive at the early stage when there are few adopters in the network, and negative when there are many.

3 Methodology

In social science, social programs are often assessed to measure the gains (or losses) of participants conditional on specific interventions. This conditional impact is commonly referred as a program's "benefit incidence". However, an individual cannot be both a participant and a nonparticipant of a same program. This is a generic problem in all casual inference (Holland, 1986). Secondly, for studies using nonexperimental data, the estimated treatment effects are confounded by selection bias (Duflo, 2004). In this study, the probable selection bias happens where motivated individuals have a higher probability of getting access to modern crop varieties (or relevant information) and have also a higher probability of adoption. The major challenge for estimation is how to take account of both observable and nonobservable preexisting differences between adopters and nonadopters in drawing inferences about the varietal programs in sub-Saharan Africa. A line of recent development in the evaluation literature have greatly increased the availability of addressing these problems and have furthered the evaluation techniques in empirical studies (Heckman, LaLonde, & Smith, 1999; Ravallion, 2008; Todd, 2008).

As one of them, the central idea of matching is to find in a large group of non-participants who are similar to the participants in all relevant pre-treatment characteristics X. Rosenbaum and Rubin (1983) suggest a use of so-called balancing scores $P(X)$ that is the function of the relevant observed covariates X such that $P(X)$ is independent of placement of treatment. In this study, $P(X) = \Pr(T = 1 | X)$ denote a household's probability of using improved maize variety, where T is a binary indicator for adopting improved variety and X is a vector of observed characteristics (at both household and community level) that determine the adoption behavior.

Compared with OLS, PSM doest not require such a parametric model and allows for estimating mean impacts without arbitrary assumptions on functional forms (Ravallion, 2008, p. 3809). This facilitates estimation in the presence of potentially complex interaction effects, which is particularly the case in this study due to its nonexperimental data and likely endogenous placement of treatment.

The use of PSM in this study, however, holds strong assumptions that which individual receives treatment – adoption of improved maize – is negligible after conditioning on a set of observed covariates. This methods, as Todd concluded (2008, p. 3890), should be adopted "only in situations where the available conditioning variables are rich enough to make the required assumption plausible". We in this study base the estimation of PS on these theoretical thoughts, as presented above.

4 Data

The data used in this study are based on a longitudinal household survey in Uganda and Kenya coordinated by Foundation for Advanced Studies on International Development (FASID). [8] The dataset consists of information at both household and community level (see Table 2). While the household questionnaire documented 10 randomly selected household in each sublocation, the community-level questionnaire recorded both current and retrospective information. The baseline data in Uganda documented an annual crop season that began in March 2003; a subsequent round followed at two year intervals. Similarly, the baseline data in Kenya recorded an annual crop season that started in February 2004 with a three year intervals for the subsequent round. We in this study use the data from the first wave survey.

Measures of adoption may indicate both the timing and extent of new technology utilization by individuals (Sunding & Zilberman, 2001). In this study, we use a discrete (binary) variable denoting if improved maize varieties is being used by a farmer during the survey period. [9] First, it is found that maize is a major staple food

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[8] FASID has undertaken the Research on Poverty, Environment, and Agricultural Technology (RePEAT) project, a large-scale survey of rural communities and farm households in East Africa. The data of Uganda was collected in the crop year 2003 and 2005 in collaboration with Makerere University; the data of Kenya was collected in the crop year 2004 and 2007 with collaboration with ICRAF and Tegemeo Institute. International Food Policy Research Institute (IFPRI) coordinated the first round survey as well. Information in details via: http://www3.grips.ac.jp/~21coe/e/index.html

[9] The definition of modern varieties (MVs) of maize is rather provisional because recycled seeds of both hybrid varieties and open pollinated varieties (OPVs) can not be differentiated by farmers. Furthermore, generic drift between hybrid varieties and OPVs exacerbates the measuring difficulties. As such, in this study, MVs refer to both hybrid varieties and OPVs.

in the two countries; approximately one third of households' cash purchasing of staple in Kenya were for maize, although this figure in Uganda is relatively lower (Table 3). Second, the adoption ratio in Kenya is almost twice as much as that in Uganda. The intensity of both fertilizer and manure for traditional and improved maize varieties in Kenya is visibly higher than the figure in Uganda. Meanwhile, the maize yields in Kenya and Uganda present striking difference; households in regions *Rift Valley* and western Kenya reported yields that are 2.5 times as much high as that in Uganda.

The active adoption of high-yield maize, however, seems to be weakly explained by prices. For example, the price for improved maize seeds in Kenya is not significantly lower than that in Uganda, although the number in the region *Rift Valley* is visibly low. Furthermore, the price ratio of fertilizer-maize is confounding because the average fertilizer-maize price ratio is lower in Kenya, denoting a high relative price of chemical fertilizer in Kenya. The depressed level of maize yield in Uganda may be attributed to the inactive adoption of modern varieties, sluggish fertilizer and labor inputs, and/or diverting inputs on other activities.

5 Findings

To estimate the propensity score (also called balancing score), whether a household adopted improved maize varieties is identified as the treatment given the observed covariates X . The estimation of propensity score is given in Table 4.[10] First, uneducated householders are found inactive in adopting improved maize seed variety. But improved education does not contribute to increased adoption of improved maize variety. Second, initial assets affect the adoption decision significantly. The distributional effects of the Green Revolution are verified. Third, the institutional settings are critical in smallholder farmer's adopting improved maize variety in both Uganda and Kenya. For example, improved availability of access to extension service in both Uganda and Kenya leads to increased adoption of modern seed varieties. Lastly, the "endogenous network diffusion hypothesis" of adoption is not verified in this study. The endogenous network, identified by ethnicity in this study,

[10] The estimation of propensity score is slightly different from a binary choice regression of adoption behavior because the selected covariates X are supposed to influence both the participation decision and the outcome variable(s).

is found insignificant in adopting agricultural technology and practices. Farmers rely on individual networks that are not necessarily based on geographic or ethnic closeness.

Several results emerge from using propensity score matching for estimating the treatment effects of adoption on yields and other concerned variables (Table 5). First, adopting improved maize variety notably leads to high yield (658.41 kg/hec.) in Kenya. But this figure is only half in Uganda (with the kernel matching scheme). Second, the adoption of improved seeds encourages more fertilizer inputs on the fields in Kenya, and the figure (89.29 kg/hectare) is almost twice as much as that in Uganda (42.16 kg/hectare). Notably, the manure intensity of improved variety in Kenya is approximately 100 times as much as that in Uganda.

Third, unlike the inactive fertilizer effects of adoption, adopting improved maize variety in Uganda results in more family and hired labor inputs. Such an effect, however, is not observed that much in Kenya. Furthermore, smallholder farmers in Uganda tend to diversify their labor inputs among staple grains, export crops (viz. coffee) and livestock. Farmers in Kenya, in contrast, are inclined to combine maize cropping and livestock, achieving in a synergistic development between cropping and livestock.

6 Sensitivity Test

As a nonparametric estimating technique, matching neither imposes functional form restrictions (such as linearity) on the outcome equations nor assumes a homogeneous treatment effect across the population. This facilitates estimation for the presence of non-experimentally placed program and potentially complex interaction effects. The use of PSM, however, holds strong assumptions that the selection is solely based on a set of observable characteristics and that all variables influencing treatment assignment and potential outcomes simultaneously are observed (Rosenbaum & Rubin, 1983). This assumption is hold only in situations where the available conditioning variables are rich enough to make the required assumption plausible (Todd, 2008, p. 3890). A line of studies find that estimates of matching estimators are sensitive to the choice of X in particular applications (Heckman, Ichimura, & Todd, 1998; Smith & Todd, 2005). These studies find that which variables are included in the estimation of the propensity sore can make a substantial difference to the performance of the estimator. [11]

In this study, the selection of covariates is based on existing theories that were reviewed in the early section. Sensitivity of the estimates to small changes is examined by adding several high-order items, as used by Dehejia (2005), and by trimming off some variables that affect the balancing property in the original specification. [12]

The results of sensitivity test are given in Table 6. Over-specification by adding unnecessary nonlinear terms probably biases the results (Zhao, 2005). But the inclusion of high-order items in this study does not affect the outcomes significantly. Meanwhile, in the experimental trimming specification by dropping off variables with regional variation, the balancing property is better satisfied, but the treatment effects do not change so much (Table 6). [13] Besides the sensitivity test, common support is shown in appended Figure 1 by graphing the kernel density estimation (in the case of both adoption and non-adoption) to test whether or not there are differences in covariates X between the treatment and non-treatment groups after conditioning on propensity score $P(X)$.

The sensitivity checks applied in empirical studies, although helpful in eliminating sensitive cases, cannot help to solve the fundamental problem that matching assumptions are inherently untestable (Zhao, 2005). In other words, the robustness of results in different specification does not mean that the conditional independence assumption is satisfied. The propensity score matching estimators may

[11] By reanalyzing a study of Dehejia and Wahba (1999), Smith and Todd (2005) find that estimates of propensity score matching are highly sensitive to both the set of variables included in the scores and the particular analysis sample used in the estimation. In his reply to ST's work, Dehejia (2005) notes that the final diagnostic must be performed to check the sensitivity of the estimated treatment effect to small changes in the specification of the balancing score.

[12] Besides the inclusion of high-order items for sensitivity check, Dehejia (2005) presents an alternative sensitivity analysis by using certain model selection criteria.

[13] Variables of price information (e.g. maize and fertilizer) are dropped off in the trimming specification. The prices of maize and fertilizer were collected at sublocation level in the FASID survey. But some of the questionnaires did not record the price information, causing a number of missing. By replacing the missing with the price in neighbored districts, segmentation of samples at regional level is unavoidable.

constantly overestimated or underestimated the treatment effect. While PSM is a potentially useful econometric tool, it does not represent a general solution to the evaluation problem (Smith & Todd, 2005). Matching performs very well in certain situation while it might be poor in others. The use of matching technique should not substitute for traditional econometric estimators, and should be "consistent with the features of the data and institutions present in a give context" (op.cit. pp. 349-350).

7 Conclusion

The objective of this paper was to explore the constraints for tapping potential agricultural productivity in Sub-Saharan Africa. Here, we examine the effects of adopting improved maize varieties on yield, fertilizer inputs and labor inputs. Several conclusions can be drawn from this study. The findings in this study respond to the current debates on enhancing food security by projecting subsidized fertilizer programs to complement the adoption of improved seed varieties. The adoption of improved maize varieties leads to significant increase in yield in countries where corresponding availability of fertilizer is viable. Nevertheless, the yield-enhancing objective can be achieved by multiple strategies. Livestock programs can complement with the seed varieties and generate an optimistic yield effects.

The comparative success in Kenya's tapping agricultural potential implies that a multisectoral approach can capture a synergy between technologies, human capital (education and health), institutional services (extension and financial services) and environmental sustainability. The agriculture-based strategy in Kenya – the farm-livestock integrated scheme – complements food security with environmental conservation, achieving in both "Green Revolution" and "Livestock Revolution" (Delgado, Rosegrant, Steinfeld, Ehui, & Courbois, 1999). [14] The development strategy matters. To conduct an agriculture-for-development strategy, there exists opening and widening pathways for Sub-Saharan Africa out of poverty, to achieve in

[14] The derived conclusion in this study should be referred carefully because the livestock programs are only successful within specific context and with dynamic perspective. Meanwhile, the synergy between farming and livestock husbandry is far beyond a combination between stall-feeding and cultivation. For example, the livestock revolution of India's diary sector during the last three decades has been largely policy induced within a closed economy environment. The competitiveness of India dairy sector to the global markets, however, is distorted by export subsidies, domestic support and prohibitive tariffs in developed countries (Sharma & Gulati, 2003).

food security, agricultural transformation and environmental sustainability (WDR, 2008).

Tables and Figures

Table 1 Selected variables for estimating propensity score

Variables in Use	Denotation	Previous Studies
Household level		
LAND_CAP	Capita-land ratio (log)	(Boserup, 1975; Lele & Stone, 1989; Salehi-Isfahani, 1988)
EDUDM*	Education	(Feder, Just, & Zilberman, 1985; Foster & Rosenzweig, 1995, 1996; Lin, 1991)
AGE	Age of head	
SEX	Gender	(Doss & Morris, 2001)
TTHM	Total population	(Feder, 1980; Feder & O'Mara, 1981)
ETHINIC*	Ethnicity	(Conley & Udry, 2001; Matuschke, 2007)
DEP_RT	Dependent ratio	
LOGASS	Log assets	
Market level		
PRC_IMP_SEED	Price of improved seeds	
PRC_IMP_MAIZ	Price ratio of improved seeds to maize	
OFFINC_GR2	farm labor income (log)	
OFFINC_GR1	Off-farm wage income (log)	
Institutional and contextual level		
IF_ASSOC	Extension service and information	(Feder & O'Mara, 1981)
IF_WITHIN	Market access	(FAO, 2007)
LAND_TENANT	Area of land sharecropped in	(Place & Hazell, 1993)
CREDIT_NPK	Credit for fertilizer (Kenya)	(Feder & O'Mara, 1981)
RATIO_EXPORT	Cultivating percentage of export crops to total cultivating area (Uganda)	(Hill, 2007)
IF_MILK	Livestock program in Kenya: Milk collection in the sublocation (Kenya)	(Otsuka & Yamano, 2005)
Geographical level		
ZONE_DM	Agro-climatic zone	(Hassan, Corbett, & Njoroge, 1998)
PRCP_SD	Agro-climatic uncertainty	

Table 2 Outlook of data

	Uganda	Kenya
Sample Areas	Most areas except northern regions	Central and Western Kenya
Samples	First wave: 94 communities. 10 households in each sublocation. Second wave: 94 communities. 10 households in each sublocation.	First wave: 100 communities, 10 households in each sublocation. Second wave: 76 communities, 10 households in each sublocation.
Survey periods	2003 for the first wave and 2005 for the second wave	2004 for the first wave and 2007 for the second wave

Source: Adapt from FASID (2004)

Table 3 Description of variables

	Kenya				Uganda		
	Nyanza	Western	Rift valley	Central	Central	East	West
Obs	175	109	221	316	327	277	320
State variables							
Incidence of adopting HYV maize	128	71	164	227	131	95	109
Maize yield (median: kg/hec)	810.04	1350.00	2165.63	720.00	800.00	778.57	500.00
Share of cash purchasing of staple cash expenditure (mean: %)	28.64	48.57	12.50	36.07	4.83	18.31	30.77
Ratio for maize to total cultivating area (mean: %)	16.57	14.42	16.72	10.90	9.33	10.68	5.58
Ratio for export crops to total cultivating area (mean: %)	3.19	2.87	0.91	6.46	5.61	4.82	3.95
Ratio of *improved* maize varieties to maize cultivation (mean: %)	57.95	53.77	68.28	60.93	36.81	29.17	31.37
Fertilizer intensity for maize (kg/hec)							
Local	32.92	77.31	90.01	49.91	5.59	2.59	33.26
Improved	24.51	31.20	22.75	35.59	1.92	0.14	48.64
Manure intensity for maize (ton/hec)							
Local	0.04	0.91	0.62	1.37	0.01	0.01	0.10
Improved	0.21	0.44	0.08	1.49	0.05	0.01	0.04

Table 3 Description of variables (cont.)

	Kenya				Uganda		
	Nyanza	Western	Rift valley	Central	Central	East	West
Market and household level							
Price of improved seeds							
Local varieties	0.44	0.29	0.20	0.36	0.28	0.31	0.28
Improved varieties	0.38	0.29	0.13	0.33	0.28	0.32	0.28
Price ratio of HYV seeds to maize	7.09	6.84	4.81	5.29	5.56	8.32	5.51
Price ratio of fertilizer/maize							
DAP	2.88	3.87	5.63	2.97	5.73	6.19	5.63
NPK	2.06	1.83	2.90	2.82	5.40	4.74	14.42
Land per capita (median)	0.89	0.63	1.59	1.25	1.25	1.00	0.92
Business, wage and salary income, of which							
Wage income	408.83	502.26	661.54	567.32	2.50	0.00	3.37
Farm labor wage	9.36	7.54	30.63	22.51	5.58	4.56	10.15
Institutional level							
Is there extension service? (%)	29.14	12.84	4.07	26.90	27.52	47.29	58.13
Is there credit for fertilizer? (%)	20.00	9.17	4.98	17.41	11.93	9.75	0.00
Has milk collection point in the sublocation? (%)	4.57	17.43	46.61	70.57	3.06	0	3.44
Is the nearest market within the sublocation?(%)	59.43	46.79	36.20	32.91	43.43	30.32	21.88

Table 4 Propensity score

Variables	Denotation	Uganda		Kenya	
		Coef.	Std. Err.	Coef.	Std. Err.
LGLAND_CAP	Land per capita (log)	0.07	0.09	0.24	0.13**
EDUDM1	Education dummy for Illiteracy	-6.24	1.33***	-5.06	0.57***
EDUDM2	Education dummy for Primary	-5.88	1.32***	-4.99	0.5*3***
EDUDM3	Education dummy for Secondary	-5.68	1.32***	-5.12	0.54***
EDUDM4	Education dummy for Tertiary	-5.46	1.34***	-4.61	0.63***
AGE	Age of head	-0.01	0.00	-0.01	0.00**
SEX	Gender of head	0.24	0.15	0.07	0.15
TTHM	Total family population	0.00	0.01	0.07	0.02***
ETHNICITY1[a]	Ethnic group	0.71	1.13	0.20	0.25
ETHNICITY2		0.03	1.10	1.17	0.31**
ETHNICITY3		0.18	1.10	0.48	0.33
ETHNICITY4		-0.12	1.09	0.31	0.24
ETHNICITY5		0.14	1.13		
DEP_RT	Dependent ratio	-0.04	0.24	-0.07	0.23
LOGASS	Initial assets (log)	0.09	0.04**	0.19	0.06***
PRC_IMP_MAIZ	Price ratio of improved seeds to maize	0.03	0.01**	-0.03	0.01***
PRC_DAP	Price of DAP	0.95	0.40**	0.08	0.30
LGOFFINC_GR1	Farm labor income (log)	-0.02	0.11	0.03	0.02
LGOFFINC_GR2	Off-farm wage income (log)	-0.03	0.05	-0.01	0.04
IF_ASSOC	There is extension service and information	0.18	0.09**	0.28	0.15*
IF_WITHIN	There is market for farm produce in sublocation	0.07	0.10	0.04	0.14
LAND_TENANT	Area of land sharecropped in	0.09	0.17	-0.81	1.97
RATIO_EXPORT	Cultivating percentage of export crops to total cultivating area (Uganda)	0.00	0.00		
CREDIT_NPK	Credit for fertilizer (Kenya)			0.34	0.19*
IF_MILK	Livestock program in Kenya: Milk collection in			0.13	0.15

Variables	Denotation	Uganda		Kenya	
		Coef.	Std. Err.	Coef.	Std. Err.
	the sublocation (Kenya)				
ZONE_DM1	Agro-climatic zone: Dry midaltitude	0.01	0.41		
ZONE_DM2	Moist midaltitude	0.21	0.41		
ZONE_DM3	Moist highland			0.14	0.14
ZONE_DM4	Cool highland	-0.30	0.39		
ZONE_DM5	Extreme water	0.61	0.72		
PRCP_SD	Agro-climatic uncertainty: the standard variation of precipitation in the past 5 years	0.00	0.00	0.00	0.00

Note: a) The variables of ethnicity in Uganda and Kenya denote different ethnic groups, which are *Nilotics*, *Bantus*, *Hamites*, *BantusII*, *HamitesII* and others in Uganda, and *Luo*, *Luhya*, *Kisii*, *Kalenjin*, *Kikuyu*, and others.

Table 5 Propensity score matching

Outcome variable	Uganda				Kenya			
	Neighbour 1	Neighbour 10	PS kernel matched	Local linear regression	Neighbour 1	Neighbour 10	PS kernel matched	Local linear regression
Yield	327.98	368.34	347.20	378.01	826.79	596.93	658.41	731.24
	(174.24)*	(112.06)***	(99.39)***	(121.85)***	(284.69)***	(290.54)**	(248.77)***	(308.71)**
Cultivating ratio of improved seeds	0.90	0.90	0.90	0.90	0.85	0.85	0.85	0.85
	(0.01)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***	(0.01)***
Fertilizer intensity (kg/hec.)								
Improved	42.16	42.16	42.16	42.16	89.29	89.29	89.29	89.29
	(22.05)*	(21.24)**	(21.41)**	(21.74)**	(14.03)***	(13.80)***	(12.99)***	(12.01)***
Local	-1.17	-6.50	-5.92	-6.21	-35.49	-38.77	-37.84	-33.99
	15.44	10.31	6.30	6.57	(12.29)***	(10.86)***	(9.88)***	(11.77)***
Manure intensity (ton/hec.)								
Improved	0.12	0.12	0.12	0.12	1.28	1.28	1.28	1.28
	0.10	0.11	0.10	0.09	(0.22)***	(0.21)***	(0.19)***	(0.20)***
Local	-0.17	-0.10	-0.09	-0.08	-0.83	-0.90	-0.88	-0.83
	(0.10)*	0.07	0.07	0.07	(0.31)***	(0.28)***	(0.24)***	(0.28)***

Table 5 Propensity score matching (cont.)

	Uganda				Kenya			
Outcome variable	Neighbour 1	Neighbour 10	PS kernel matching	Local linear regression	Neighbour 1	Neighbour 10	PS kernel matching	Local linear regression
Labor inputs on maize, of which…								
Family labor input (hours)[1]	184.44	216.50	216.91	215.01	87.09	94.83	92.41	95.48
	(62.50)***	(51.31)***	(58.35)***	(56.36)***	66.93	(54.39)*	(52.96)*	62.03
Hired labor and machine (USD)[1]	16.60	16.04	16.38	16.61	10.53	8.37	11.27	11.16
	(4.44)***	(4.11)***	(4.09)***	(4.14)***	12.95	13.24	11.58	10.41
Labor inputs on export crops, of which								
Family labor (Hours)	25.56	24.16	19.66	18.94				
	24.27	17.24	17.53	19.47				
Hired labor and machine (USD)	-0.14	0.40	0.22	0.51	-8.95	-23.86	-27.27	-24.41
	1.61	1.21	1.00	1.17	25.86	20.39	21.61	28.60
Labor inputs on livestock , of which								
Family labor (Hours)	238.72	138.26	134.09	131.89	513.00	297.44	277.60	314.33
	174.36	116.11	112.92	103.96	(296.78)*	213.85	186.26	203.20
Hired labor and machine (USD)	4.06	1.14	1.60	1.83	7.43	5.69	5.27	5.07
	7.15	7.38	6.23	5.37	(3.79)**	(3.47)*	(3.24)*	3.37

Notes: (a) Standard errors are given in parentheses; PSM standard errors are obtained by bootstrapping (100 repetitions). Common support is imposed by dropping 5 percent of the treatment observations at which the pscore density of the control observations is the lowest. (b) ***, ** and * indicate significance levels of 1, 5 and 10 percent respectively.

Table 6 Sensitivity test with changing specification

Treatment effects	Uganda			Kenya		
	Original specification	Higher-order specification [a]	Trimmed specification [b]	Original specification	Higher-order [a]	Trimmed specification [b]
Yield	347.20	340.57	330.94	658.41	658.99	555.74
	(99.39)***	(111.47)***	(111.23)***	(248.77)***	(252.47) ***	(243.86)**
Fertilizer intensity of MV seeds (kg/hec.)	42.16	42.16	41.82	89.29	90.04	88.57
	(21.41)**	(22.10)*	(23.62)*	(12.99)***	(15.13)***	(13.52)***
Manure intensity of MV seeds (ton/hec.)	0.12	0.12	0.12	1.28	1.25	1.28
	(0.10)	(0.11)	(0.12)	(0.19)***	(0.23)***	(0.21)***
Family labor inputs on maize (hours)	216.91	208.07	242.96	92.41	96.05	88.04
	(58.35)***	(46.49)***	(55.24)***	(52.96)*	(58.95)*	(47.61)*

Notes: (a) The higher-order specification includes the square items of age, land per capita (log form), and initial assets (log form). (b) The prices of maize and fertilizer were collected at sublocation level in the FASID survey. But some of them failed to answer the price questions, causing a number of missings. By replacing the missings with the price in neighbored districts, segmentation of samples at regional level is unavoidable. In the trimmed specification, those variables are dropped off. (c) The treatment effect is computed using kernel matching. (d) Standard errors, in parentheses, are computed using the bootstrap with 100 repetitions.

Appendix A

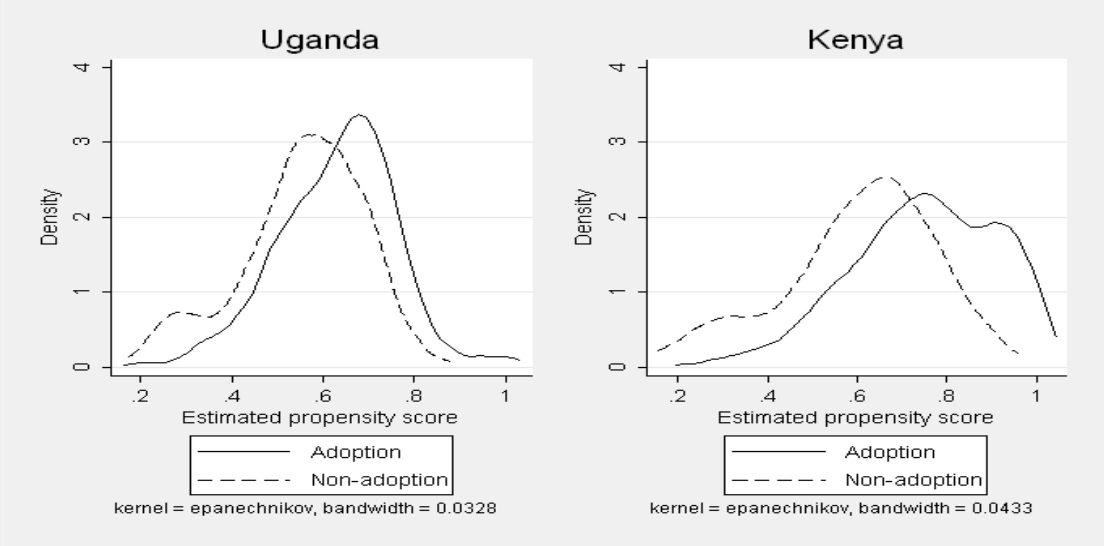
Table 7 Definition of agro-climatic zone in Uganda and Kenya

Zone	Kenya				Uganda			
	Elevation (masl)[a]	Total precipitation, March-August (mm)	Temperature (Cent.) March-August		Elevation (masl)	Total precipitation, March-August (mm)	Temperature (Cent.) March-August	
			Min.	Max.			Min.	Max.
Lowland tropics								
Dry lowland	>700	300-500	20.0	30.0	<1000	300-500	20.4	29
Moist lowland	<400	>500	20.0	31.0	<1000	>500	21.1	29.4
Midaltitude zone								
Dry midaltitude	700-1400	300-500	14.0	33.0	1000-1800	<500	14.2	25.8
Moist midaltitude	1110-1500	>500	13.0	30.0	1000-1800	>500	13.8	26.4
Transitional zone								
Dry transitional zone	1100-1700	<500	11.0	27.0				
Moist transitional zone	1200-2000	>500	11.0	29.0				
Highland Tropics								
Dry highland	1600-2300	<500	8.0	26.0	>1800	<500	10.6	24.2
Moist highland	1600-2700	>500	7.0	27.0	>1800	>500	11	24.7
Cool highland	2000-2900	<1000	5.0	22.0	>2000	<1000	7	20
Water stress	400-1100	<400	16.0	32.0	<1000	<300	19	30

Note: a) masl: meters above sea level. b) The use of transitional zone is referred to the 'revised classification of maize-specific zones' (Hassan, 1998, p. xvii); the classification in Uganda is referred to the 'initial classification of maize-specific. Neither of them is found in the dataset used in this study'

Appendix B

Figure 1 Kernel density estimation to test common support



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