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The Possibility of a Rice Green Revolution in Large-scale Irrigation Schemes in Sub-Saharan Africa

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Abstract

This paper investigates the potential of and constraints to a rice Green Revolution in Sub-Saharan Africa's large-scale irrigation schemes, using data from Uganda, Mozambique, Burkina Faso, Mali, Niger, and Senegal. The authors find that adequate irrigation, chemical fertilizer, and labor inputs are the key to high productivity. Chemical fertilizer is expensive in Uganda and Mozambique and is barely used. This is aggravated when water access is limited because of the complementarities between fertilizer and irrigation. Meanwhile, in the schemes located in four countries in West Africa's Sahel region, where water access is generally good and institutional support for chemical fertilizer exists, rice farmers achieve attractive yields. Some countries' wage rate is high and thus mechanization could be one solution for this constraint. Improvement of credit access also facilitates the purchase of expensive fertilizer or the employment of hired labor.

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The possibility of a rice Green Revolution in large-scale irrigation schemes in Sub-Saharan Africa

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1. Introduction

The importance of rice in Sub-Saharan Africa (SSA) is increasing rapidly (Otsuka and Kijima, 2010). The consumption of rice is increasing, and the imbalance between domestic production and consumption has been growing in SSA. The total milled rice production in SSA increased from 2 million tons in 1961 to 16 million tons in 2009 (FAO, 2009). At the same time, milled rice imports into SSA increased from 0.5 million tons in 1961 to 10 million tons in 2009 due to inadequate local production to meet the growing demand. SSA accounts for a third of global rice imports at a cost of more than US$4.3 billion per year, which otherwise could be used to finance infrastructure development and other productive purposes. Therefore, national and international attention now centers on how to increase rice production in SSA as an important component of the region's strategies on food security.

One possible strategy to achieve this goal is to take an Asian-style approach as Asia has successfully achieved a rice Green Revolution over the last three decades (Otsuka, 2006; Otsuka and Kalirajan, 2005). At the same time, however, many studies are skeptical about this strategy (Spencer, 1994; World Bank, 2008). Among many reasons, the central reason behind the skepticism is the under-development of irrigation in the region (Hayami and Godo, 2005; Spencer, 1994; World Bank, 2008). Although large- and middle-scale irrigation played a significant role in facilitating the diffusion of fertilizer-responsive high-yielding modern varieties (MVs) in Asia, high investment costs, declining rice prices, and the failures of past large-scale government-led gravity irrigation projects are believed to be the main reasons for the reluctance of donors and governments to invest in large-scale irrigation in SSA (Inocencio et al., 2007).

However, with the passage of time, conditions for growing irrigated rice have changed dramatically. The price of rice is expected to increase in the long run (USDA 2008). In addition, the reform process initiated in the past two decades by African countries has tremendously changed the institutional and policy environment for growing rice in large irrigation schemes. For example, the Office du Niger irrigation scheme in Mali is now touted as a "success story" (Aw and Diemer, 2005). In fact, a recent assessment of existing irrigation schemes by Inocencio et al. (2007) found that the costs of irrigation projects are not significantly higher in SSA than in other regions and that irrigation investments can provide good returns under the right conditions. Therefore, it is worth examining empirically whether large-scale irrigation schemes can be a cradle for a rice Green Revolution (GR) in SSA, as was the case in Asia. However, the number of micro-level studies in SSA is limited.[1]

This study aims to investigate the potential of SSA's large-scale irrigation schemes for a rice GR in the region as well as the conditions for achieving the potential. We use household-level data collected in six SSA countries: Uganda, Mozambique, Burkina Faso, Mali, Niger, and Senegal. The study sites are large-scale irrigation schemes and are considered as areas with high potential for rice cultivation in terms of availability of water and agro-climatic conditions. However, we observe wide variations in the availability of irrigation water, cultivation practices, and rice productivity within a scheme or between schemes. This provides us with a good opportunity to examine under what conditions the potential of an irrigation scheme can be fully realized.

[1] Sakurai (2006) examines the possible constraints to lowland rain-fed rice cultivation in Côte d'Ivoire and Kijima et al. (2006, 2008, 2011) investigate the potential of upland NERICA cultivation in Uganda. However, none of them are about rice cultivation in large- or medium-scale irrigation.

This paper is organized as follows. After the explanation of the study countries and study sites in Section 2, we descriptively analyze the characteristics of rice production at each irrigation scheme in Section 3. In Section 4, in order to identify the possible constraints to rice production statistically, we estimate the regression function showing the determinants of rice yield and input use for Uganda and Mozambique, for which data sets are available for regression analyses for our purposes. Section 5 concludes by providing the policy implications.

2. Study sites and data

The six countries for our study come from two regions: East Africa (Uganda and Mozambique) and the Sahel region of West Africa (Burkina Faso, Mali, Niger, and Senegal). Table 1 shows the production and ecology of the rice sector in each country. Generally speaking, the rice sector is less developed in East Africa than in the Sahel region in terms of the extensiveness of irrigated area as well as productivity. Irrigated area consists of only 2% in both Uganda and Mozambique, with an average rice yield of 1.51 tons per ha and 1.12 tons per ha, respectively. Meanwhile, the four Sahelian countries show higher proportions of irrigated area and higher average yields, and, among them, Niger's and Senegal's figures look superior and as good as those of Asian countries.

Our analyses rely on the following ten irrigation schemes (Figure 1).

- Doho rice scheme in Uganda
- Chokwe scheme in Mozambique
- Kou valley, Sourou, and Bagré schemes in Burkina Faso
- Ninon and N'Débougou in Mali
- Say and Daibéri in Niger

- Senegal River Valley in Senegal

Table 2 summarizes the major characteristics of each scheme and the features of the survey data. In addition to the differences in water delivery systems, size, climatic conditions, management body, and proximity to city, one notable difference can be found in supporting institutions. Neither Uganda nor Mozambique provides support for fertilizer purchase, agricultural credit, and output procurement to rice farmers. Meanwhile, all four Sahelian countries received an informal (Burkina Faso and Mail) or formal (Niger and Senegal) subsidy on fertilizer. In addition, in Mali and Senegal, there exist savings and loan programs or farmer organizations that facilitate group purchase of fertilizer. Niger's government provides price support (Kore, 2006). Generally speaking, institutions are more supportive in the four Sahelian countries than in the two East African countries.

In all surveys except the one in Niger, data were collected by random or stratified random sampling methods to obtain representative farmers in each irrigation scheme.[2] The sampling unit is farming households. We use only rice farmers in the schemes for our analyses. The Doho's survey was conducted by one of the authors in 2007.[3] The International Rice Research Institute conducted the survey in Chokwe in 2007. The survey of four Sahelian countries was conducted by the Africa Rice Center and its country partners in 2005-06 or in 2006-07. Since the surveys were conducted independently with their own research focus, the available variables are not completely comparable. Moreover, as of 2010, the data sets for the four Sahelian countries are not yet cleaned for the estimation of the determinants of yield and input use. Hence, the

[2] The sampling in the Doho rice scheme is stratified by irrigation blocks. The other studies use simple random sampling.
[3] See Nakano (2009) for more details.

regression analyses in Section 4 rely on only the data from Uganda and Mozambique. However, all the surveys still share some key common variables for descriptive analyses in Section 3.

3. Descriptive analyses

Features of surveyed irrigation schemes

Table 3 compares rice production and production environments among the surveyed irrigation schemes. In order to investigate the importance of irrigation water for rice cultivation, we divide farmers in Doho and Chokwe into those who have good access to irrigation water and those who do not.[4] Since we do not have a corresponding variable for the Sahelian studies, we show the change in water access at each scheme since the last crop season. Although some show deterioration and others show improvement, we observed in our survey that water access in all surveyed schemes in the four Sahelian countries was generally good. Some might have claimed deterioration but this seem does not to mean a severe water shortage as they used to have sufficient water and the deterioration was marginal. Hence, in descriptive analyses, we treat all the Sahelian schemes as "good access." As another case of good water access, we show data of an irrigated rice-growing area in Asia, in our case, Laguna Province in the Philippines in 1976, 1982, and 1987 (Hayami and Kikuchi, 2000). This enables us to assess the potential of SSA's irrigated rice in comparison with Asia when they were at a similar stage of the Green Revolution. The similarity of the stage is determined based on the type of modern varieties cultivated by farmers at each study site (either MV1, MV2, or

[4] In Doho, farmers facing main canals are classified into the group of good access and, otherwise, the group of not-good access. In Chokwe, those who claimed "receiving enough water in 2007" were classified into the group of good access.

MV3).[5] They are reported in the second row of the table. A comparison reveals that Doho's current stage corresponds to the period between 1976 and 1982 in Laguna,[6] Chokwe does so in 1976, and the Sahelian schemes do so somewhere between 1982 and 1987 in Laguna.

One of the most important findings from Table 3 is the importance of irrigation water to the productivity of rice. As long as water access is good, the paddy yield at both Doho and Chokwe (3.2 tons per ha and 2.2 tons per ha, respectively) is not much lower than the yield at the corresponding stage in Laguna. It is worth noting also that, although Doho and Chokwe have cultivated rice for a long time (since the late 1970s in Doho and since the 1950s in Chokwe), they achieved this level of yield in the survey year. This is consistent with the finding in agronomy that claims that irrigation water maintains soil fertility and rice can be cultivated sustainably without suffering a yield decline. The importance of irrigation is also found in the Sahelian schemes. Water access is generally good in all the Sahelian schemes and they achieve very attractive yields. Among them, the Senegal River Valley shows amazingly high yield (5.3 tons per ha). Note also that the irrigated area of this scheme is huge (60,000 ha). These facts imply that the availability of sufficient irrigation water is a key to achieving yield similar to or even higher than Asia and it is not impossible to achieve this on a large scale like the case of the Senegal River Valley.

[5] The first-generation MVs (MV1s) were released from the mid-1960s to the mid-1970s and were more fertilizer-responsive than traditional varieties. Yet, they were susceptible to pests and diseases. The second-generation MVs (MV2s), which were designed to ensure stable yields by incorporating multiple pest and disease resistance, were released from the mid-1970s to the mid-1980s. The third-generation MVs (MV3), which incorporated better grain quality and stronger host-plant resistance, were released from the mid-1980s to the late 1990s.

[6] The major rice varieties cultivated in DRS were modern varieties introduced by a Chinese aid agency in the 1970s and crossed with local varieties in the nearby experiment station. Although we cannot be decisive, we may be able to categorize them into MV1 or MV2.

Related to this, we would like to stress also that the varieties from Asia or the ones based on Asian parental varieties perform well in SSA under irrigated conditions. The most popular variety in Chokwe is ITA312, which was developed by the International Institute of Tropical Agriculture (IITA) and it has its parental variety in Asia. The next popular variety, C4, is a variety developed in the Philippines. In Niger, IR1529 from IRRI is used. The modern varieties cultivated in Senegal use *Oryza sativa* germplasm imported from Asia, are widely accepted, and achieve superior yield.[7]

Another important finding is that low fertilizer use is one of the constraints to increasing yield in Doho and Chokwe. Farmers in Doho and Chokwe apply much less chemical fertilizer than farmers in the Philippines or those in the Sahelian countries. One of the reasons for the low input use at both study sites may be the high price of chemical fertilizer. The real prices of nitrogen in terms of kilograms of paddy are 4.3 in Doho, 7.9 in Chokwe, but 3.7 to 3.5 in Laguna or 1.5 in Senegal. Moreover, the low fertilizer use and resulting low yield are associated with the availability of irrigation water. In areas where the water supply is not reliable, farmers hesitate to use fertilizer as the marginal product of fertilizer depends on the availability of sufficient water (Estudillo and Otsuka, 2006). In Chokwe, farmers apply 23 kg of nitrogen per hectare when they receive sufficient irrigation water, whereas they apply only 13 kg when they receive insufficient irrigation water. Therefore, the availability of irrigation water is likely to have not only a

[7] In 1994, three improved varieties, Sahel 108, Sahel 201, and Sahel 202, were released by AfricaRice and its national partners after screening more than 1,000 lines of *Oryza sativa* germplasm accessions imported from Asia (AfricaRice, 2006). The Asian parents of the short-duration improved variety Sahel 108 are IR305, Babawee, and IR36, which came from IRRI. The medium-duration varieties Sahel 201 and 202 were developed using lines that originated, respectively, from Sri Lanka and IITA. The Sahel varieties rapidly gained producers' acceptance in Senegal and Mauritania as they replaced earlier introduced varieties. Currently, these three varieties occupy about 70% of irrigated rice area in the Senegal River Valley in both Senegal and Mauritania (AfricaRice, 2006).

direct impact on rice yield but also an indirect impact through the increase in fertilizer application.

On the other hand, by African standards, fertilizer use in the Sahelian schemes is remarkably high. In fact, in Niger, the average fertilizer application rates are well above the recommended rate, which is 400 kg/ha. This can be partly attributed to a relatively low fertilizer price and institutional support in these countries. According to national statistics, the ratio of urea price to paddy price is 2.5 in Burkina Faso, 1.3 in Mali, and 1.6 in Niger, which are close to the fertilizer price ratios in Table 3.[8] Note that the countries with strong institutional supports for fertilizer (see Mali, Niger, and Senegal in Table 2) show very low fertilizer price ratios. This ratio is not disadvantageous at all compared with the ratio of about 3.5 in Laguna in 1976-82 and 2 in major rice producers in Asia such as India and Pakistan in 2001 (Minten et al. 2006).

Related to this, we would like to stress that farming practices appear to be homogeneous in the Sahelian schemes. Regarding chemical fertilizer application, the standard deviation relative to the mean (i.e., the coefficient of variation) is much smaller than that in Doho and Chokwe. This may be one of the benefits of a well-managed irrigation scheme. This homogeneity implies that a serious constraint to rice production in the Sahel relative to Uganda and Mozambique might not exist, and thus many farmers use a large amount of chemical fertilizer to achieve yield comparable with yield in Asia.

Table 3 also shows labor use and the real daily wage in terms of kilograms of paddy. [9] A notable feature is found in Chokwe. The wage rate is higher and the labor

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[8] Chemical fertilizer reported in Table 3.3 consists of urea and other kinds of complete fertilizer packages.

[9] Note that these are the real wages in terms of paddy. If we compare wages in US$ at official exchange rates of the survey years, they become 2.94 (Doho, Uganda), 1.73

input, excluding bird scaring and the proportion of hired labor (75 or 77 days), is lower than those in Asia, especially in the 1970s (105 days). In Asia, the introduction of labor-using modern varieties increased labor demand, and that increase was met by an abundant supply of landless wage laborers (David and Otsuka, 1994; Hayami and Kikuchi, 2000). Generally speaking, few landless households exist in Africa. Although exchange labor between farming households is a common practice in Chokwe, coordination of the timing of the exchange is difficult during peak labor periods such as transplanting and harvesting/threshing periods because of the synchronization of such peak periods among farmers. For these reasons, the wage rate becomes high, especially during the peak labor periods, and this may hinder farmers in Chokwe from applying a sufficient amount of labor for cultivating MVs.

Under such circumstances, household size relative to farm size could affect production performance in the Sahelian countries. For example, among them, Burkina Faso's and Niger's relative wage rate is higher than that of Mali. This may stem from Mali's larger household size and smaller farm size than the others. We expect that the labor constraint may be more severe in Burkina Faso and Niger than in Mali. Meanwhile, other household characteristics such as the age of the household head and average years of schooling of adult household members are similar between schemes. Therefore, these factors do not seem to be important in explaining the difference in performance across countries.

(Chokwe, Mozambique), 1.90 (Burkina Faso), 1.90 (Mali), 1.89 (Niger). The wages in Sahelian countries become higher than Chokwe, Mozambique partly due their higher paddy prices (thus, resulting in lower real wages) and partly due to overvaluation of CFA franc. Doho's wage is still much higher than the other countries presumably due to the fact that wage labor is used mainly in labor intensive works such as transplanting and harvesting and the peak labor season is overlapped in short period among the farmers as irrigation rotation is not well coordinated.

Competitiveness of rice production in surveyed irrigation schemes

We now turn to the costs and returns of the study schemes presented in Table 4 in order to show the profitability and competitiveness of irrigated rice of SSA against *imported* rice from Asia. Similar to Table 3, Doho and Chokwe are divided into two groups depending on water access. For the comparison among schemes, all figures are converted to US$ using the official exchange rate in the survey year. Since the necessary data for the imputation of labor and owned capital costs was not made for the Sahelian irrigation schemes, we show only net return or income, while we show profit as well for Doho and Chokwe. Senegal is not included as the data are not ready for this analysis yet.

In Doho and Chokwe, where water access is not good, the gross value of output is low due to low yield, whereas the total cost does not change regardless of water access conditions. Therefore, income and profit become lower when water access is not good. Particularly, profit in Chokwe in the case of unfavorable water access becomes negative, indicating that these farmers cannot be competitive with imported rice in local markets. To examine this point more clearly, we show the production cost per ton of milled rice in comparison with the international f.o.b. price in the survey year in the lower part of the same table. Note that the unit cost would be higher if we included the cost of irrigation (hence, generous for Doho and Chokwe to judge the competitiveness) and that the price for imported rice in local markets would be higher due to transportation costs (hence, generous for Asia). Nevertheless, those figures give some idea of the competitiveness of the irrigated rice of Doho and Chokwe.

According to the figures, although some divergence exists in the international price (US$290-335), generally speaking, domestic irrigated rice seems to be able to offer a lower price in local markets if water access is good and thus productive (US$299 in Doho and US$302 in Chokwe). This implies that, under proper management, large-scale irrigation can provide good returns as emphasized by Inocencio et al. (2007). Although we cannot perform a similar exercise for Sahelian countries, noting relatively high net returns in all schemes except Bagré, their competitiveness should also be high.[10]

In summary, descriptive analyses indicate that irrigated rice of large-scale irrigation schemes has potential to achieve high yield and thus to be competitive if farmers have good access to irrigation water and use adequate crop management practices. Note that such efficient rice farming is achieved by small farmers, as in the case of Asia (see Table 3 for farm size). In the following section, using data from Doho and Chokwe, we conduct more detailed statistical analyses, to explore what kind of constraints hinder adequate management for high yield and how they are related to water access.

4. Regression analyses

Methodology

In order to examine the conditions to achieve high yield at our study sites, we estimate the yield function and input use functions. In a structural form, yield per ha can be expressed as a function of inputs per ha, given technology and the management ability of farmers:

$$y_i = \beta_0 + x_i\beta_1 + H_i\beta_2 + u_i,$$

where y is yield per ha, X is a vector of inputs, and H is a vector of household and farming characteristics. Our econometric concern, however, is that inputs are endogenous variables and OLS is not an appropriate approach. To circumvent this problem, we apply

[10] Bagre's low income (US$166) stems from the much lower paddy price in local markets (92 Fcfa) than the other schemes (128 and 119 Fcfa). Meanwhile, excessively high income in Mali (US$1,000 and $983) is due to the high paddy price (208 and 192 Fcfa).

the instrumental variable (IV) method, regressing input use on the exogenous variables that farmers cannot change at least in the short run in accordance with the current season's production decision:

$$x_i = \gamma_0 + H_i\gamma_1 + Z_i\gamma_2 + v_i,$$

where *x* is the use of a particular input in *X* and *Z* is a vector of the exogenous variables that serve as identifying instrumental variables for *X* in the yield function. In this approach, the first-stage regressions can be regarded as the estimation of the reduced-form input use functions. We use the results of input use functions to identify the constraints to input use. If the factor markets function perfectly, the level of inputs should be determined solely by input prices relative to the output price, technology, and farmers' farming ability (as the determinants of marginal returns), but not by factor endowments and wealth. Thus, if we find that any endowments and wealth have significant coefficients, we can conjecture that there are imperfections in the factor market. Combining such results with the results of the yield function, we assess how such constraints affect yield.

However, in Doho, we could not find appropriate identifying instrumental variables to explain the variation in possible endogenous variables. Therefore, we turned to the estimation of the reduced-form yield function. Hence, our yield function and input use function for Doho are expressed as

$$y_i = \delta_0 + H_i\delta_1 + Z_i\delta_2 + w_i,$$

$$x_i = \gamma_0 + H_i\gamma_1 + Z_i\gamma_2 + v_i,$$

Although we cannot estimate the direct and indirect impact of irrigation water on paddy yield separately in this approach, we can still estimate the aggregate impact of irrigation water on yield, which is the major interest of our analysis.

Variable construction

For Chokwe, the input use vector (*X*) consists of (1) chemical fertilizer, (2) labor, (3) proportion of hired labor, (4) machinery use, and (5) the method of crop establishment. For Doho, we use only the first three inputs, as the use of machinery is uncommon and the common method of crop establishment is transplanting.

For both sites, the vector *H* consists of (1) plot size, (2) availability of irrigation water, (3) human capital, and (4) season dummy (if the survey covers multiple seasons). Since the size of the cultivated area is primarily determined by the availability of water at the initial stage of farming, we can practically treat it as an exogenous variable. Irrigation water, which is managed by the state, and farm location are assumed to be exogenously given to the farmers. The average schooling years and age of the household head are included to capture the ability of farm management and experience, which would affect yield at a given level of inputs. Since these are pre-determined, we treat them as exogenous variables.

As identifying instrumental variables, we include (1) land endowment, (2) other asset endowment, (3) membership in a cooperative, (4) access to market and extension service, and (5) gender of the household head. The list of variables and detailed definitions for each survey are presented in Table 5. The factor prices and output price are not included because our data sets were collected in one area in a particular year where prices are practically the same for all the households.

Input use function

We begin with the interpretation of results in Chokwe in Table 6. Besides the OLS results, when the dependent variable is either censored or binary, we show the Tobit or Probit results for checking robustness of the estimation results. The results of the NPK function in Chokwe indicate that farmers do not apply chemical fertilizer unless they receive sufficient irrigation water, due to the strong complementary relationship between them. The positive and significant coefficient of the value of the non-agricultural asset in Chokwe seems to imply that farmers with good credit access can purchase sufficient amounts of chemical fertilizer. The availability of cash on hand, which is measured by the proportion of salary earners, significantly increases fertilizer application until the proportion becomes 20% in Chokwe. Based on these results, we argue that improvement in access to irrigation water and in credit/cash would increase fertilizer application.

Labor input is related positively to household size and negatively to the size of the cultivated area in Chokwe. These determinants would not be significant if farmers were able to hire labor as much as they wished. Although the proportion of hired labor increases with the size of the cultivated area (positive and significant coefficient), it would not reach the level that farmers wished to apply. Another reason for the labor constraint could be the credit constraint for payment to hired labor as implied by the positive and significant coefficient of the non-agricultural asset value in hired labor regression, because a piece-rate cash payment is the most common labor contract in Chokwe.[11]

[11] During field interviews, we encountered several farmers who claimed that they could not hire labor since they did not have cash on hand.

In Table 6, we also show the regression results for the use of a tractor, thresher, and transplanting in Chokwe. Similar to the other results, the coefficient of the non-agricultural assets is positive and significant for the use of either tractors or threshers, suggesting the importance of credit access for renting these machines. The probability of tractor use increases with the average schooling years partly because tractors (all 4-wheels in Chokwe) must be managed and operated skillfully and partly because the opportunity cost of educated labor is high, which induces substitution of tractors for labor. A puzzling result is the U-shape relationship between the use of threshers and the proportion of salary earners, which is opposite to the case of NPK. Farmers are less likely to practice the transplanting method as the size of the cultivated area becomes larger because transplanting is a more labor-intensive method of crop establishment than direct seeding.

Table 7 shows the regression results of input use functions in Doho. The negative and significant coefficient of the distance from the main channel to the intake of the strip for the cost of current inputs indicates that farmers apply more current inputs when they have better access to irrigation water, which is consistent with the results of Chokwe. Therefore, irrigation water has not only a direct impact on rice yield but also would have an indirect positive impact through an increase in current input application. The size of the unirrigated cultivated area in Doho has an inverted U-shape relationship to fertilizer application, with the peak at 3 ha. Considering that only 15% of sample households cultivate more than 3 ha, it is almost a positive relationship, which may imply that farmers with larger upland cultivated area may have better access to credit or cash and hence can purchase more fertilizer.

Similar to Chokwe, the results for labor and hired labor imply that there is a labor constraint in Doho because of an inactive labor market. The proportion of salary earners has a negative impact on total labor input, with the peak of the U-shape relationship at a much higher value (21%) than the average (2%), which is consistent with our intuition because the more salary earners a household has, the less dependent the household is on rice farming. Puzzling results are the U-shape relationship between total labor use and the average years of schooling, and the inverted U-shape relationship between total labor use and the size of unirrigated cultivable area, for which we cannot find any good explanations.

Yield function

Table 8 summarizes the results of the yield function in Chokwe. The OLS results of the linear approximation model and the corresponding IV results (models (1), (2)) indicate that management ability and experience do not have much impact on yield, particularly in the IV model, presumably because they do not have direct impacts but indirect impacts on yield through their effect on the change in endogenous input variables. Hence, in models (3) and (4), we remove them from our yield function and use them only in the first-stage regressions.

The test statistics for the IV approach of our final model presented in the lower part of Table 5 indicate that inputs may suffer from endogeneity (the chi-square test for endogeneity at the 15% significance level) but they are significantly predicted by the instrumental variables (first-stage F test) that can be considered as exogenous to the model (chi-square test for overidentification), providing confidence in the validity of the model specification (Wooldridge, 2002).

A key finding is that chemical fertilizer, labor, and irrigation water are the crucial factors that affect yield. Fertilizer application has a positive impact on yield. Yield is low when insufficient irrigation water is received. Labor input is also a crucial input. On the other hand, mechanization does not have much impact on yield increases. This feature is also observed in Asia as machine power can be replaced by animal power or human labor to some extent (David and Otsuka, 1994).[12] The negative and significant coefficient of the size of cultivated area indicates that higher yield is achieved under a smaller scale operation, which is also consistent with the observation in Asia that small farmers contributed to the rice Green Revolution.

In Table 9, we show the estimation results of reduced-form yield functions in Doho. In model (1), we use the distance from the main channel to the intake of the strip and the distance from the intake of the strip to each plot as proxies for the availability of irrigation water. In model (2), we use water depth (cm) at the critically important stage of flowering, and treat it as an exogenous variable. The distance from the main channel to the intake of the strip has a negative and significant coefficient on yield. Water depth has a significant and positive impact on yield. Both results indicate the importance of irrigation water for rice productivity. According to model (2), a 1-cm increase in irrigation water raises paddy yield by 0.13 ton per hectare.

5. Concluding remarks

This paper investigated the potential of and constraints to the rice Green Revolution in SSA's large-scale irrigation schemes, using data from Uganda, Mozambique, Burkina

[12] Although tractor power can be replaced by human labor, not all kinds of human labor activities can be replaced by tractor power (for example, crop establishment and harvesting). Thus, a labor shortage can still be a constraint.

Faso, Mali, Niger, and Senegal. The results of regression analyses for Uganda and Mozambique reveal the crucial importance of irrigation water for rice productivity. When irrigation water is available, both study sites achieve high yield. Furthermore, the availability of irrigation water may have both a direct impact on rice yield and an indirect impact through an increase in fertilizer application. Since the conditions for water access are generally good in the four Sahelian countries, farmers achieve attractive yield with sufficient application of chemical fertilizer. In many schemes, Asian varieties or varieties with an Asian origin perform well under irrigated conditions. This implies that proper management of irrigation schemes for timely and sufficient water distribution, together with variety transfer from Asia, is one of the key strategies to increase rice production in large-scale irrigation schemes.

The sufficient use of chemical fertilizer in the four Sahelian countries seems to be attributed not only to their good water access but also to the institutional support for fertilizer purchase. Unless the cost of support is unduly high, this kind of support may be effective in Uganda and Mozambique, where no such support exists yet. In addition, our regression results for Uganda and Mozambique imply that an improvement in credit access would help cash-constrained farmers purchase chemical fertilizer.

We also find that labor shortages are another critical constraint to the achievement of high productivity. The results in Uganda and Mozambique indicate that improvement in credit access could encourage hiring wage labor. The development of varieties with shorter maturity could be another solution as they would spread out the peak season’s labor demand. Moreover, it is worth considering a strategy to substitute machines for labor in areas where the relative wage rate is high. A challenge is the strategy to promote this relatively expensive equipment. Further investigation is needed to see whether collective ownership (maybe through a co-op) can be a solution. In addition, it is clear that, unless local repair shops are accessible to local farmers, dissemination would be limited.

Although small-scale irrigation development seems to be a current trend in SSA among aid organizations, our analyses show that large-scale irrigation schemes also have high potential under proper management and are equally important. When the Comprehensive Africa Agriculture Development Programme (CAADP) called for investment in improved water control for 15.9 million ha by 2030, the proposed share of the large-scale irrigation area (including new and rehabilitation investment) still consists of about 17%, while the proposed share of small-scale irrigation area is 14%, that of wetlands and inland valley bottoms is 23%, and that of water harvesting and rainfed areas is 45% (World Bank, 2007).[13] Thus, large-scale irrigation schemes are as important as other means such as small-scale schemes and rainfed area development. The lessons drawn from our study sites are important for the development of strategies for SSA's rice Green Revolution.

[13] Large scale refers to an irrigated area of 1,000 ha and more, whereas small scale refers to an area of more than 1 ha but less than 100 ha in the report.

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Table 1 Basic Statistics on Rice Production in Survey Countries

Country	Uganda	Mozambique	Burkina Faso	Mali	Niger	Senegal
Harvested rice area (000 ha)	93.0	179.0	51.0	451.0	27.8	95.0
Production (t)	140	201.0	95.2	877.0	76.5	264.5
Yield (t/ha)	1.51	1.12	1.87	1.94	2.75	2.78
Rice production ecology (%)						
Irrigated wetland	2	2	46	22	80	50
Rainfed wetland	53	59	50	13	0	40
Dry land	45	39	4	1	0	0
Deepwater and mangrove	0	0	0	64	20	10

Source
Balasubramanian et al, 2007

Table 2 Characteristics of Irrigation Schemes and Survey Data

Country	Uganda	Mozambique	--------- Burkina Faso ---------			-------------- Mali -----------		--------- Niger ---------		Senegal
Scheme	Doho	Chokwe	Kou Valley	Sourou	Bagré	Niono	N'Débou-gou	Say2	Daibéri	Senegal River Valley
Survey year	2007	2007	2005-06	2005-06	2005-06	2005-06	2005-06	2005	2005	2006/07
Irrigation system	River & gravity	Dam & gravity	River & gravity	River & diesel pump	Dam & gravity	Dam & gravity	Dam & gravity	River & electrical pumping	River & electrical pumping	River & electrical pumping
Potential irrigated area (ha)	1,000	26,000	n.a.	35,000	8,158	900, 000		70,000		240,000
Current irrigated area (ha)	1,000	4,000	1,400	3,200	1,885		11,757	186	295	60,000
Annual rainfall (mm)	1,150	650	1,200	800	900	550		400 -700	200-400	300-400
Management body	Farmer organizations	Para state	Farmer organizations	Para state	Para state	Para state	Para state	Para state	Para state	Para state
Fertilizer subsidy	No	No	No public fertilizer program, small-scale program by NGOs*			No public fertilizer program, small-scale program by NGOs* Support by the Office du Niger through farmer organizations.**		30% subsidy rate on fertilizer price		50% subsidy rate on fertilizer and herbicide prices
Credit program	No	A small-scale program targeted to large-scale farmers only.	No			Group purchases of fertilizer through non-public savings and loan programs and farmer organizations		No public credit program		Credit available through the CNCAS (agricultral bank) and some rural private micro-finance institutions
Other related policies								Price support provided through government purchase of a 75-kg sack of paddy at 10,000 CFA		Input voucher available (delivered by the National Extension Agency, SAED)
The nearest large city	Mbale	Maputo	Bobo Dioulasso	Ouaga-dougou	Ouaga-dougou	Bamako	Bamako	Niamey	Niamey	Saint Louis
Distance to the nearest large city (km)	30	220	30	250	2	330	346	56	105	101
Sampling unit	Rice farming household	Rice farming household	Rice farming household	Rice farming household	Rice farming household	Rice farming household	Rice farming household	Rice farming household	Rice farming household	Rice farming household
Sampling method	Stratified random	Random	Random	Random	Random	Random	Random	Purposive	Purposive	Random
Sample size	288 (103)**	176	78	40	30	49	50	60	50	100

* Subsidy was introduced after the food crises in 2008. ** The field agents of the office du Niger approve annual fertilizer budgets of farmer organizations in good standing with local financial institutions. It assists also farmers bidding and bulk purchase through farmer organizations. ** *Sample size declines to 103 when we include water depth .

Table 3 Paddy Yields, Input Use per Hectare, and Input Prices at the Study Sites and in Laguna in the Philippines

Country	Uganda		Mozambique		-------------Burkina Faso------------			------------Mali-----------		----------Niger---------		Senegal	-------Philippines-----		
Scheme	Doho		Chokwe		Kou Valley	Sourou	Bagré	Niono	N'Débougou	Say2	Daibéri	Senegal River Valley	Laguna		
Survey year	2007		2007		2005-06			2005-06		2005-06		2006-07	1976	1982	1987
Water access	Facing the main channel	Not facing the main channel	Receive enough water	Do not receive enough water	Deteriorated access to water	Mixed results	Improved access to water	Improved access to water	Improved access to water	Mixed results	Deteriorated access to water		n.a.		
Rice variety	MV1 and MV2[a]		MV1 (ITA312, C4)		MV2 (FKR14) MV3 (FKR28)			MV3 (Gambiaka Kogoni 91-1)		MV1(IRI529) (MV3(WITA 8)		MV3(Sahel 108, 201, 202)	MV1	MV2	MV3
Paddy yield (t/ha)	3.2 (1.3)	2.7 (1.7)	2.2 (1.2)	1.3 (1.0)	3.2 (0.7)	3.6 (1.7)	3.2 (1.2)	3.2 (1.6)	3.1 (1.3)	4.3 (1.5)	3.6 (1.2)	5.3	2.8	3.6	4.3
Input use															
Nitrogen (kg/ha)	1.6 (3.5)	2.0 (5.6)	23 (27.6)	13 (24.5)								114	58	80	94
Chemical fertilizer (kg/ha)					309 (209.6)	318 (72.7)	299 (88.7)	248 (109.0)	241 (107.3)	446 (201.0)	460 (183.7)	313			
Labor (person day/ha)[c]	179 (76.5)	173 (103)	75 (72.3)	77 (78.0)									105	80	69
Proportion of hired labor (%)	55	52	36	35									71	70	83
Proportion of HHs using hired labor (%)					84.6	90.0	86.7	100	46	93.3	82.0				
Animal use (%)	0	5	47	52	97.4	56.5	43.3	97.8	91.8	91.4	90.0		78	73	86
Tractor use (%)	0	0	51	76	0	43.5	6.7	2.2	0	0	0		100	98	98
Input price															
Price of Nitrogen in terms of kg of paddy	4.3		7.9		2.3	2.4	3.5	1.2	1.6	1.7	1.8	1.5	3.7	3.5	2.1

Labor wage in terms of kg of paddy	10		12		7.8	8.4	10.9	4.8	5.2	7.9	7.9		9.8	15	13.2
Household characteristics															
Total farm size (ha)	2.11	2.27	1.5	2.5	1.0	1.3	1.9	5.4	1.4	3.9	4.0	1.56			
	(1.7)	(1.8)	(2.2)	(4.4)	(0.2)	(1.1)	(0.2)	(3.5)	(1.2)	(2.4)	(2.0)				
Age of hh head	46.2	47.1	51.6	51.9	54.3	40.2	43.4	52.4	52.2	47.8	49.1				
	(11.6)	(14.1)	(14.6)	(12.8)	(14.3)	(8.3)	(7.7)	(13.7)	(12.1)	(11.0)	(14.6)				
Average schooling year of hh member	6.0	5.2	4.27	4.59									5.0		6.5
	(2.7)	(3.0)	(2.02)	(1.8)											
Schooling year of hh head					4.0	3.3	3.0	4.9	4.0	2.1	1.6				
					(4.5)	(3.4)	(3.0)	(3.5)	(4.1)	(3.2)	(3.6)				
HH size			8.23	7.04	18.8	11.6	11.9	21.3	19.7	10.3	10.6		5.9		5.3
			(3.92)	(3.45)	(7.0)	(6.8)	(4.7)	(14.3)	(15.4)	(4.6)	(6.4)				
Sample size	111	177	151	25	78	40	30	49	50	60	50				

Standard deviations in parentheses.
(a) The major rice varieties cultivated in Doho were modern varieties introduced by a Chinese aid agency in the 1970s and crossed with local varieties at the nearby experiment station. Although we cannot be decisive, we may be able to categorize them into MV1 or MV2.
(b) Village-level questions about relative access to irrigation water compared to the previous year (mixed results refer to a situation where an equal number of villages point to improved and deteriorated access to irrigation water).
(c) Excluding labor for bird scaring.

Local price of paddy per kg in survey year
Uganda, Doho: 505 Ush
Mozambique, Chokwe: 3.9 MT
Burkina Faso, Kou Valley: 128 Fcfa, Sourou: 119 Fcfa, Bagré: 92 Fcfa
Mail, Ninon: 208 Fcfa, N'Débougou: 192 Fcfa
Niger, Say: 126 Fcfa, Daibéri: 126 Fcfa

Table 4 Costs and Returns in Study Schemes (in US$)

	Uganda		Mozambique		----- Burkina Faso -----			------ Mali -----		----- Niger -----	
	Doho		Chokwe		Kou Valley	Sourou	Bagré	Niono	N'Débou gou	Say2	Daibéri
	2007		2007			2005-06		2005-06		2005-06	
	Facing the main channel	Not facing the main channel	Receive enough water	Do not receive enough water	Deteriorated access to water	Mixed results **	Improved access to water	Improved access to water	Improved access to water	Mixed results **	Deteriorated access to water
Costs and returns (per ha)											
Gross output value (paddy) (A)	952	786	307	203	790	841	552	1,262	1,298	1,030	858
Seed	33	29	9	12	16	15	42	28	22	0	0
Fertilizer	4	5	23	14	150	228	216	140	152	227	149
Pesticide	6	4	3	2	2	29	11	7	2	0	0
Hired labor	271	269	80	71	32	153	63	51	90	293	292
Family labor, imputed	261	274	85	78							
Capital (tractor, thresher, animal) paid out	0	2	49	74	26	48	55	36	49	72	55
Capital (tractor, thresher, animal) imputed	0	0	23	24							
Total paid-out cost (B)	281	280	163	174	226	473	386	261	315	593	497
Total cost (C)	574	583	272	276							
Net return (A)-(B)	671	506	143	29	564	368	166	1,000	983	438	361
Profit (A)-(C)	377	203	35	-73							
Unit production cost of milled rice (US$/ton)	299	358	302	407							
Int'l rice price (US$/t f.o.b.) in survey year											
Thai 2nd grade		335						291			
Thai A1 super		275						219			
Pakistan 25%		290						235			
Vietnam 5%		313						255			
Sample size	111	177	144	32	78	40	30	49	50	60	50

Chokwe: The milling cost of 1,765 MT per ton of paddy and 65% recovery rate are assumed.

Exchange rates are: Chokwe: $1= MT 27 in 200 Doho: Exchange rate: $1=Ush 1,716 in 2007West Africa: $1=Fcfa 526 in 2005-06 average

Table 5 Definition of the Variables at Each Study Site

Study site	Chokwe	Doho
Dependent variable (y)	Paddy yield (t/ha)	Paddy yield (t/ha)
Input use (X)		
Fertilizer	Total amount of N+P+K (kg/ha)	Total cost for fertilizer (100 thousand Ush/ha)
Labor	Total labor input (days/ha)	Total labor input (days/ha)
Hired labor	Proportion of hired labor	Proportion of hired labor (%)
Machinery	Tractor (=1 if use tractor)	
	Threshing machine (=1 if use threshing machine)	
Seeding	Crop establish method (=1 if transplanted; =0 if direct seeding)	
Environment and HH characteristics (H)		
Availability of irrigation water	Insufficient irrigation (=1 if hh receives insufficient water)	Directly measured water depth in the plot (cm)
	Downstream parcel (=1 if the plot is located downstream)	Distance from the main channel to the intake of the strip (km)
		Distance from the intake of the strip to each plot (km)
Plot size	Size of the cultivated area in the sample plot (ha)	Size of the cultivated area in the sample plot (ha)
Human capital endowment and farming ability	HH size	Number of adult household members
	Female-headed household (=1 if female-headed)	Female-headed household (=1 if female-headed)
	Average schooling years of adult household members	Average schooling years of adult household members
	Average schooling years of adult household members squared	Average schooling years of adult household members squared
	Age of head	Age of head
	Age of head squared	Age of head squared
Season dummy		2nd season 2007 (=1 if 2nd season 2007)
Instrumental variables (Z)		
Land endowment	Unirrigated owned area (ha)	Unirrigated cultivated area (ha)
	Unirrigated owned area (ha) squared	Unirrigated cultivated area (ha) squared
	Irrigated owned area (ha)	Other cultivated area in DRS (ha)
	Irrigated owned area (ha) squared	Other cultivated area in DRS (ha)
Other assets and access to cash	Value of non-agricultural assets	
	Proportion of salary earners	Proportion of salary earners
	Proportion of salary earners squared	Proportion of salary earners squared
Membership of co-op	Member of water user group (=1 if member)	
	Member of agriculural association (=1 if member)	
	Member of cooperative (=1 if member)	

Table 6 Determinants of Input Use in Chokwe

	NPK (kg/ha)		Labor (days/ha)	Prop. hired lab (%)	Use of tractor (dummy)		Use of thresher (dummy)		Transplanting (dummy)	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	OLS [a]	Tobit	OLS [a]	OLS [a]	OLS [a]	Probit	OLS [a]	Probit	OLS [a]	Probit
Size of cultivated area	0.748	0.488	-10.301	0.049	0.039	0.264	0.043	0.522	-0.050	-0.303
in the sample plot (ha)	(0.60)	(0.26)	(2.80)***	(2.74)***	(1.58)	(1.97)**	(3.76)***	(2.07)**	(2.46)**	(2.76)***
Insufficient irrigation	-14.140	-29.610	21.356	0.005	0.249	0.903	-0.008	-0.274	-0.006	-0.105
	(2.52)**	(2.93)***	(1.28)	(0.06)	(2.22)**	(2.39)**	(0.15)	(0.18)	(0.07)	(0.25)
Downstream parcels	-1.092	-3.265	5.694	0.028	-0.116	-0.396	-0.093		0.047	0.412
	(0.18)	(0.33)	(0.32)	(0.33)	(0.97)	(1.03)	(1.71)*		(0.49)	(0.84)
HH size	-1.095	-1.542	5.448	-0.010	-0.002	-0.018	-0.007	0.054	0.008	0.054
	(2.06)**	(1.82)*	(3.46)***	(1.33)	(0.20)	(0.55)	(1.45)	(0.50)	(0.97)	(1.41)
Ave sch years	1.360	3.946	-0.531	0.030	0.166	0.548	-0.010	-1.033	-0.056	-0.229
	(0.44)	(0.78)	(0.06)	(0.67)	(2.69)***	(2.75)***	(0.35)	(1.88)*	(1.12)	(0.86)
Ave sch years sq	-0.065	-0.288	0.202	0.001	-0.014	-0.047	0.000	0.067	0.006	0.027
	(0.22)	(0.61)	(0.23)	(0.29)	(2.42)**	(2.49)**	(0.09)	(1.57)	(1.32)	(0.98)
Age of head	0.330	0.694	0.702	0.000	0.008	0.026	0.003	0.162	-0.003	-0.053
	(0.82)	(1.01)	(0.59)	(0.00)	(0.99)	(0.97)	(0.76)	(0.72)	(0.48)	(0.85)
Age of head sq	-0.002	-0.005	-0.015	0.000	-0.000	-0.000	-0.000	-0.002	0.000	0.000
	(0.39)	(0.71)	(1.15)	(0.02)	(0.67)	(0.63)	(0.70)	(0.95)	(0.16)	(0.70)
Female-headed HH	-4.116	-8.785	-1.446	-0.151	-0.040	-0.161	-0.033	-0.693	0.156	0.780
	(1.01)	(1.32)	(0.12)	(2.58)**	(0.49)	(0.63)	(0.87)	(0.86)	(2.37)**	(2.29)**
Unirrig owned area	7.975	26.641	45.845	-0.162	0.010	-0.227	0.020	1.229	0.211	1.289
	(0.98)	(1.69)*	(1.89)*	(1.37)	(0.06)	(0.24)	(0.26)	(0.43)	(1.59)	(2.07)**
Unirrig owned area sq	-0.936	-3.543	-3.497	0.037	0.022	0.132	0.000	0.210	-0.026	-0.166
	(0.80)	(1.30)	(1.01)	(2.19)**	(0.92)	(0.69)	(0.02)	(0.67)	(1.38)	(1.93)
Irrig owned area	2.798	4.160	-1.035	0.010	-0.002	-0.025	0.015	0.353	-0.041	-0.138
	(3.03)***	(2.99)***	(0.38)	(0.71)	(0.13)	(0.41)	(1.74)*	(1.93)	(2.71)***	(2.06)**
Irrig owned area sq	-0.037	-0.054	0.031	-0.000	-0.000	-0.000	-0.000	-0.007	0.001	0.002
	(2.92)***	(2.85)***	(0.84)	(2.29)**	(0.46)	(0.06)	(2.94)***	(2.58)***	(3.13)***	(0.97)
Value of non-ag assets	0.243	0.302	0.120	0.005	0.004	0.014	0.002	0.032	-0.001	-0.003
	(3.09)***	(2.51)**	(0.51)	(3.97)***	(2.31)**	(2.51)**	(3.17)***	(2.07)**	(0.52)	(0.62)
Prop of salary earners	55.349	109.958	-22.513	-0.908	-0.276	-1.462	-1.119	-35.771	0.663	3.266
	(1.63)*	(1.83)*	(0.22)	(1.85)*	(0.41)	(0.57)	(3.59)***	(2.00)**	(1.21)	(1.14)
Prop of salary earners sq	-145.635	-288.810	-65.124	2.186	0.531	4.187	2.577	61.922	-1.753	-7.843
	(1.81)*	(1.90)*	(0.27)	(1.88)*	(0.33)	(0.58)	(3.48)***	(1.65)	(1.35)	(1.06)
Member of WUG	0.836	-1.499	10.837	0.009	-0.133	-0.386	-0.031	-2.297	0.064	0.266
	(0.22)	(0.25)	(0.97)	(0.17)	(1.77)*	(1.67)*	(0.88)	(2.41)**	(1.04)	(0.94)
Member of ag assoc	5.358	9.253	-12.212	-0.027	0.112	0.342	0.029	2.116	-0.002	-0.062
	(1.34)	(1.47)	(1.03)	(0.47)	(1.40)	(1.42)	(0.79)	(2.16)**	(0.04)	(0.22)
Member of co-op [b]	-8.749	-10.675	-68.939	0.087	0.065		0.578		0.693	
	(0.37)	(0.31)	(0.97)	(0.25)	(0.14)		(2.63)***		(1.79)	
Constant	-28.088	-106.541	-31.980	0.262	-0.597	-3.304	0.023	-18.219	0.677	0.624
	(1.23)	(2.50)**	(0.47)	(0.79)	(1.31)	(1.77)	(0.11)	(0.67)	(1.83)*	(0.28)
First-stage F test for IV	2.99		1.78	4.35	2.02		3.60		1.81	
	[0.00]***		[0.03]***	[0.00]***	[0.01]**		[0.00]***		[0.03]**	
Observations	176	176	176	176	176	176	176	176	176	176

* significant at 10%; ** significant at 5%; *** significant at 1%

[a] Results of the first-stage estimation of the instrumental variable analysis for the estimation of paddy yield function in Table 3.

[b] Probit analysis cannot include an explanatory variable that predicts the dependent variable perfectly. For this reason, this variable is dropped from the probit estimation.

Table 7 Determinants of Input Use in DRS

	Cost for fertilizer (100 thousand Ush/ha)	Labor (days/ha)		Prop. hired lab (%)
	(1)	(2)	(3)	(4)
	OLS	Tobit	OLS	OLS
Plot size (ha)	-0.334	-0.34	-84.357	0.094
	(2.63)***	(2.67)***	(2.56)**	(0.94)
Distance from main channel to the intake of the strip (km)	-0.048	-0.05	-7.652	-0.011
	(2.46)**	(2.55)**	(1.51)	(0.72)
Distance from the intake of the strip to each plot (km)	0.073	0.075	-41.326	0.089
	(0.68)	(0.70)	(1.49)	(1.06)
Number of adult household members	-0.02	-0.02	7.849	-0.017
	(1.82)*	(1.85)*	(2.80)***	(1.93)*
Ave sch years	0.016	0.016	-17.087	0.029
	(0.65)	(0.65)	(2.74)***	(1.54)
Ave sch years sq	-0.001	-0.001	1.428	-0.001
	(0.63)	(0.60)	(2.88)***	(0.47)
Age of head	-0.003	-0.004	-4.312	-0.027
	(0.25)	(0.34)	(1.55)	(3.21)***
Age of head sq	0.000	0.000	0.036	0.000
	(0.03)	(0.12)	(1.30)	(3.11)***
Female-headed HH	0.061	0.066	61.067	0.01
	(0.70)	(0.76)	(2.70)***	(0.15)
Unirrig owned area	0.172	0.183	26.412	0.03
	(3.92)***	(4.12)***	(2.32)**	(0.82)
Unirrig owned area sq	-0.023	-0.025	-3.596	-0.001
	(3.56)***	(3.80)***	(2.16)**	(0.16)
Irrig owned area	-0.031	-0.04	-36.419	0.229
	(0.41)	(0.52)	(1.85)*	(3.82)***
Irrig owned area sq	0.023	0.025	5.385	-0.045
	(1.19)	(1.30)	(1.06)	(2.92)***
Prop of salary earners	-1.122	-1.174	-759.96	0.688
	(1.37)	(1.43)	(3.58)***	(1.06)
Prop of salary earners sq	2.16	2.298	1,754.21	-1.342
	(1.16)	(1.23)	(3.65)***	(0.92)
2nd season	0.034	0.029	-30.864	-0.023
	(0.88)	(0.73)	(3.03)***	(0.73)
Constant	0.776	0.793	351.69	0.96
	(3.08)***	(3.14)***	(5.38)***	(4.86)***
Observations	288	288	288	279
R-squared	0.13		0.19	0.19

Absolute value of t statistics in parentheses

* significant at 10%; ** significant at 5%; *** significant at 1%

Table 8 Determinants of Paddy Yield in Chokwe (structural form estimation)

	(1) OLS	(2) IV	(3) OLS	(4) IV
NPK [a]	0.005	0.020	0.006	0.022
	(1.32)	(1.90)*	(1.56)	(2.02)**
NPK sq				
Labor [a]	0.003	0.006	0.003	0.008
	(2.19)**	(1.74)*	(2.33)**	(2.06)**
Labor sq				
Prop of hired labor [a]	0.693	-0.595	0.712	-0.386
	(2.72)***	(0.67)	(2.89)***	(0.49)
Use of tractor [a]	-0.011	0.063	-0.000	0.207
	(0.06)	(0.10)	(0.00)	(0.29)
Use of thresher [a]	1.085	1.829	0.983	1.483
	(2.79)***	(1.59)	(2.57)**	(1.36)
Transplanting [a]	0.214	-0.480	0.217	-0.369
	(0.90)	(0.57)	(0.92)	(0.47)
Size of cultivated area in the sample plot	-0.083	-0.147	-0.078	-0.126
	(2.02)**	(2.30)**	(1.93)*	(2.06)**
Insufficient irrigation (relative freq.)	-0.810	-0.686	-0.787	-0.694
	(2.94)***	(1.93)*	(2.87)***	(1.81)*
Downstream parcels	-0.551	-0.354	-0.627	-0.459
	(2.01)**	(1.02)	(2.34)**	(1.34)
Av. schooling years of working mem	0.194	0.187		
	(1.71)*	(1.30)		
Av. schooling years of working mem sq	-0.018	-0.015		
	(1.59)	(1.10)		
Age of HH head	-0.002	-0.008		
	(0.09)	(0.38)		
Age of HH head sq	0.000	0.000		
	(0.10)	(0.22)		
Constant	1.220	1.817	1.538	1.536
	(2.14)*	(1.78)*	(5.68)***	(1.99)**
Edogeneity test (chi-sq) [b]	6.46		9.36	
	(0.37)		(0.15)	
First-stage F test		All significant		All significant
Overidentification test (chi-sq) [c]		4.26		6.88
		(0.89)		(0.80)
Observations	176	176	176	176

* significant at 10%; ** significant at 5%; *** significant at 1%

[a] Instrumented variable. Identifying instruments are the variables used in Table 4. Table 4 shows the first-stage regression results for model (5) of this table.

[b] Durbin-Wu-Hausman endogeneity test

[c] Sargan's overidentification test

Table 9 Determinants of Paddy Yield in Doho (reduced-form estimation)

	(1) OLS	(2) OLS
Water depth (cm)		0.135
		(2.15)**
Distance from main channel to the intake of the strip (km)	-0.271	
	(3.04)***	
Distance from the intake of the strip to each plot (km)	0.291	
	(0.60)	
Plot size (ha)	-0.836	-1.596
	(1.44)	(1.51)
HH size	0.012	-0.031
	(0.23)	(0.30)
Unirrig owned area	0.468	0.407
	(2.34)**	(1.08)
Unirrig owned area sq	-0.066	-0.057
	(2.26)**	(1.05)
Irrig owned area	0.276	0.412
	(0.79)	(0.38)
Irrig owned area sq	-0.049	-0.13
	(0.55)	(0.21)
Prop of salary earners	-3.016	-8.305
	(0.81)	(1.17)
Prop of salary earners sq	9.566	20.75
	(1.13)	(1.16)
Ave sch years	0.018	0.122
	(0.16)	(0.53)
Ave sch years sq	0	-0.007
	(0.04)	(0.32)
Female-headed HH	0.42	0.263
	(1.06)	(0.34)
Age of head	-0.066	-0.063
	(1.36)	(0.51)
Age of head sq	0.001	0
	(1.17)	(0.38)
Season (2007 2nd)	-0.701	
	(3.92)***	
Block dummy	No	No
Constant	4.768	3.531
	(4.15)***	(1.23)
Observations	288	103
R-squared	0.14	0.14

Absolute value of t statistics in parentheses
** significant at 5%; *** significant at 1%

Figure 1 Location of Irrigation Schemes