Transferability of Green Revolution in Sub-Saharan Africa: Impact Assessment of Rice Production Technology Training in Northern Ghana

Xu He\(^1\)* and Takeshi Sakurai\(^1\)

This paper examines the transferability of Green Revolution technologies in Sub-Saharan Africa through the assessment of a technology training project in Northern Ghana. The main results are as follows: First, the training project successfully improved the adoption rates of four technologies: dibbling in line/drilling, bund building/repairing, modern varieties, and fertilizer usage. Second, the adoption rates became higher in villages where longer time had passed since the training. Third, inter-village diffusion of technology took longer time than intra-village one.

Key words: Ghana, technology adoption, rice production

1. Introduction

Driven by urbanization, decreasing international rice price and diet change, rice is becoming a more and more important staple food in Sub-Saharan Africa (SSA) (Balasubramanian et al., 2007; Larson et al., 2010). Although rice production in SSA has been rising since 2000, this increment is mostly brought about by area expansion. Nevertheless, domestic rice production in SSA countries falls short of their consumption demand, making them reliant on large importation of rice (Seck et al., 2010). Such high dependence on importation causes concerns about food security.

Ghana is one of the typical such SSA countries. Rice has become the second most consumed cereal in Ghana, following Maize. Yet, at least 60% of domestic consumption is met by imports (FAO, 2016), mostly from Thailand and Vietnam (USAID, 2012), while average yield of domestic rice production remains low: 2.75 Mt/ha under rain-fed condition where the bulk of production occurs (MoFA, 2015). Therefore, the enhancement of rice productivity, particularly under rain-fed condition, is given high priority in the agricultural policy in this country.

It is well known that the Green Revolution in Asia was made successful by the diffusion of modern technologies for rice production (David and Otsuka, 1994; Hazell and Ramasamy, 1991; Barker and Herdt, 1978). Then, whether such successes are duplicable in SSA countries, where rain-fed rice production is dominant, has become a critical question. Investigations into the possibility and difficulty of an Asia-type Green Revolution in SSA have already been done by many studies, for instance, Otsuka et al. (2013), Diao et al. (2008), Sakurai (2006), and deGraft-Johnson et al. (2014).

However, there is a paucity of data that allow us to evaluate the impacts of mutually reinforcing technologies given a diffusion pathway on the adoption rate of Green Revolution technologies. We undertake this task in this paper by exploiting data from JICA’s Sustainable Development of Rain-fed Lowland Rice Production Project from 2009 to 2014 in Ghana. The project promoted a package of rice farming technologies to local farmers through technology training. It contained two parts: (i) technology demonstration and (ii) participation in rice production on the demonstration farms. Specifically, we assess if this intervention can raise rice farmers’ adoption rates of modern farming technologies, and what kind of diffusion pathway is more effective to spread the technologies.

Thus, the following three questions will be answered empirically: Firstly, what are the determinants of households’ technology adoption decision? Through this, we can see if JICA’s project has increased adoption rates of rice technologies. Secondly, is there any difference between the impacts of within-village technical diffusion and inter-village technical diffusion? Lastly, we also want to test the speed of technology diffusion. On the adoption rates, we hypothesize that JICA’s technology training increased them, especially for modern inputs. As for the diffusion speed, we hypothesize that it is more rapid in the case of within-village diffusion than in the case of inter-village diffusion.

\(^1\) The University of Tokyo
Corresponding author*: he-xu562@g.ecc.u-tokyo.ac.jp
The rest of this paper is organized as follows: Section 2 briefly introduces the structure of dataset and presents descriptive statistics. Section 3 explains framework of empirical analysis. Section 4 expounds the results from empirical analyses. Conclusions of this study based on these results are presented in section 5.

2. Data and Descriptive Statistics

1) Survey design and sampling structure

From July 2009 to July 2014, Sustainable Development of Rain-fed Lowland Rice Production Project was implemented by JICA in both Northern and Ashanti regions of Ghana. This project selected villages for rice production training through technology demonstration and participation in rice production on demonstration farms (note that the village selection was not random). For this study, we focused on the Northern Region only.

At the time of our data collection in April-May 2013, JICA was implementing the project in 15 villages: they were distributed equally in three districts namely Tamale Metropolitan, East Gonja, and West Mumprusi. We chose all the 15 JICA villages for our study and additionally 15 non-JICA villages were randomly chosen around the 15 project villages from 1/50,000 scale topographic sheets.

Thus, 10 villages were selected in each district, which consist of 2 JICA villages where JICA started the project in 2010 (early JICA villages, or group 1), 2 non-JICA villages around the early JICA villages (group 2), 3 JICA villages where JICA started the project in 2012 (late JICA villages, or group 3), and 3 non-JICA villages around the late JICA villages (group 4). Then, we randomly selected 10 rice producing households in each village. As a result, total number of sample households was 300 spread over 30 villages. Tables 1 and 2 summarize the classification of the villages.

| Table 1. Village groups |
|-------------------------|
| Project Year | JICA’s Technology Intervention? |
|              | Yes | No |
| Early (2010)  | G1 (6 villages) | G2 (6 villages) |
| Late (2012)   | G3 (9 villages) | G4 (9 villages) |

2) Descriptive statistics

(1) Adoption rates of improved technologies

Table 3 shows the adoption rates of technologies in the package after the intervention: modern varieties, fertilizer usage, dibbling, drilling, harrowing using tractor, and bund building/repairing. Generally, the adoption rates are higher in group 1 villages.

| Table 3. Tech. adoption rates after intervention in 2012 |
|--------------------------------------------------------|
| Technologies | G1 | G2 | G3 | G4 | Total |
|---------------|----|----|----|----|------|
| Bund building | 40.0% | 21.7% | 12.6% | 6.7% | 24.0% |
| Harrowing with tractor | 25.5% | 25.0% | 11.5% | 7.8% | 15.8% |
| Modern varieties | 63.6% | 46.7% | 51.7% | 37.8% | 48.6% |
| Jasmine variety | 41.8% | 23.3% | 6.9% | 12.2% | 18.5% |
| Dibbling in line | 23.6% | 25.0% | 4.6% | 11.1% | 14.4% |
| Drilling | 12.7% | 3.3% | 3.5% | 0.0% | 4.1% |
| Use of fertilizer | 92.7% | 56.7% | 57.5% | 57.8% | 64.0% |
| No. of observations | 55 | 60 | 87 | 90 | 292 |

Meanwhile, adoption rates of these six improved technologies before the intervention are estimated based on households’ recall, as given in Table 4. We can see huge differences in adoption rates of bunding and harrowing existed in G1 and G2 even before this intervention. Therefore, for impact identification, it is necessary to control for the adoption status before the intervention.

| Table 4. Tech. adoption rates before intervention in 2009 |
|--------------------------------------------------------|
| Technologies | G1 | G2 | G3 | G4 |
|---------------|----|----|----|----|
| Bund building | 30.9%** | 10.0%* | 2.3% | 1.0% |
| Harrowing with tractor | 41.8%** | 21.7% | 13.8% | 8.9% |
| Modern varieties | 38.2% | 53.3% | 49.4% | 43.3% |
| Dibbling in line | 16.4% | 16.7% | 5.6% | 15.6% |
| Drilling | 9.1% | 3.3% | 2.3% | 1.1% |
| Use of fertilizer | 74.6% | 53.3% | 62.1% | 65.6% |

Note: "**" and "*" indicate that the adoption rate is statistically different from that of G4 at the significance level of 0.1% and 5% respectively. There was no Jasmine adopter as of 2009 (refer to footnote 3).

(2) Characteristic of households and villages

As we have mentioned before, the selection of JICA villages was not random. It may cause endogeneity problems if we use groups of villages as key exogenous variables. Thus, in order to investigate any potential severe selection bias among four groups, we compare the means of essential variables using t-test, as shown in Table 5.

The results reveal that only a few characteristics show significant differences among the four groups. By
comparing JICA villages and non-JICA villages (i.e. G1-G2 and G3-G4), it is hardly conjectured that any systematic difference in rice production potential determined the technology adoption. Variables mean mean mean mean GI-G2 G3-G4 GI-G3 G2-G4 difference in rice production potential determined the and G3-G4), it is hardly conjectured that any systematic comparing nCA villages and non-nCA villages (i.e. G1-G2 intervention makes the dependent variable contain 4 values depicting status variation/transition (see Table 6). Thus, Multinomial Probit (MNP) model is adopted to estimate the impact of nCA’s technology training on households’ dataset, “Jasmine” is a new variety that was introduced by JICA in the technology training project.

### Table 5. Descriptive statistics of characteristics and mean comparison among groups

| Variables                                      | Village Groups |       |       |       |       |       |       |
|------------------------------------------------|----------------|-------|-------|-------|-------|-------|-------|
| Village Level Variables                        |                |       |       |       |       |       |       |
| Distance to Tamale (km)                        | 11.018         | 10.467| 9.448 | 10.467|
| Distance to nearest JICA villages (km)        | 1.385          | 1.576 | 0.894 | 1.191 |
| Wage rate (GHC/day)                            | 47.264         | 46.034| 45.788| 50.787|
| Number of adult labor force in the HH          | 6.509          | 6.533 | 5.483 | 6.067 |
| Ratio of HH members engaged in off-farm jobs   | 0.101          | 0.101 | 0.054 | 0.095 |
| Total farm size (acres)                        | 21.285         | 27.153| 29.404| 38.215|
| Mean walking time from home to rice plots (minutes) | 11.491        | 8.068 | 11.153| 9.011 |
| Rice cultivation experience (years)            | 0.429          | 0.400 | 0.284 | 0.309 |
| At least one plot has clay soil (dummy)        | 0.310          | 0.267 | 0.268 | 0.238 |
| At least one plot is on flat land (dummy)      | 0.858          | 0.679 | 0.693 | 0.820 |
| Maize farm size (acres)                        | 4.382          | 3.800 | 5.628 | 4.472 |
| Household Level Variables                      |                |       |       |       |       |       |       |
| Household size                                 | 11.018         | 10.467| 9.448 | 10.467|
| Education level of HH head (years)             | 1.385          | 1.576 | 0.894 | 1.191 |
| Age of HH head (years)                         | 47.264         | 46.034| 45.788| 50.787|
| Number of adult labor force in the HH          | 6.509          | 6.533 | 5.483 | 6.067 |
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Note: *** and * indicate that the means are statistically different at 0.1% and 5% significance level respectively. GHC stands for Ghanaian Cedi.

### 3. Framework of Analysis

1) **Multinomial Probit (MNP) model**

The combination of adoption statuses before and after the intervention makes the dependent variable contain 4 values depicting status variation/transition (see Table 6). Thus, Multinomial Probit (MNP) model is adopted to estimate the impact of JICA’s technology training on households’ technology adoption.

#### Table 6. Technology adoption category

| Adoption before intervention | Adoption after intervention | Category | $j$ value |
|------------------------------|----------------------------|----------|-----------|
| No                           | No                         | Never adopt | 0        |
| Yes                          | No                         | Dis-adopter | 1        |
| No                           | Yes                        | Adopter   | 2        |
| Yes                          | Yes                        | Always adopt | 3       |

The MNP model is given below:

\[
y_{ij}^* = x_i^T \beta_j + \epsilon_{ij} \ldots (1)
\]

\[
y_i = j \text{ if } y_{ij}^* = \max(y_{i0}, y_{i1}, y_{i2}, y_{i3}) \ldots (2)
\]

\[
P(y_i = 2 | x_i) = P(y_{i0} > y_{i1}, y_{i2} > y_{i3}) =
\]

\[
P(\epsilon_{i0} > \epsilon_{i1}) > x_1(\beta_0 - \beta_2, \epsilon_{i0} - \epsilon_{i1}) > x_1(\beta_2 - \beta_3, \epsilon_{i0} - \epsilon_{i3}) \ldots (3)
\]

where $x_i$, is a vector of household’s characteristics and group dummy variables (g1, g2, g3, g4). Since group 4 is the non-JICA villages that got the least influence from the intervention, it is set as the base group so that we can examine the impacts as follows:

- **G1-G4**: To see the impact of technology demonstration and 3 years of technology diffusion within JICA villages.
- **G2-G4**: To see if there is technology spillover from JICA villages to Non-JICA villages.
- **G3-G4**: To see the impact of technology demonstration and 1 years of technology diffusion within JICA villages.

In addition, by setting group 3 as the base group, G1-G3 will be the impact of technology diffusion within villages, which depends on time after the demonstration.

2) **Probit model**

Meanwhile, among modern rice varieties recorded in the dataset, “Jasmine” is a new variety that was introduced by JICA in the technology training project. To estimate
project’s effectiveness in improving its adoption, Probit model is utilized, where the dependent variable is a binary dummy variable of Jasmine adoption.

4. Results

1) Estimation results of MNP model

Regression results of MNP model are reported in columns (1) – (5) of Table 7. The numbers are the marginal effects computed at the means. We show only the results of adopters (j=2) with “never adopter” (j=0) being the base category because the focus of this paper is the impact on the transition from non-adoption to adoption.

To shed light on the impact of JICA’s technology training project, we firstly focus on the marginal effects of group 1, group 2, and group 3. From the marginal effects of group 1, we can see that technology demonstration combined with 3 years of within-village diffusion significantly increased the probabilities of adopting four rice production technologies: bund building/repairing, dibbling/drilling, modern rice varieties, and fertilizer. Specifically, 3-year technology diffusion within JICA villages contributes to an 18% increase in adopting bund building/repairing at a 5% level of significance. Moreover, at a 1% level of significance, it leads to a 24% increase of dibbling/drilling, a nearly 20% increase of planting modern varieties, and a 13% increase in using fertilizers. However, in the case of harrowing using tractor, the marginal effect of group 1 is positive but not significant. The latter finding implies that the adoption rate of harrowing using tractor cannot be increased by the demonstration, even after three years of within-village diffusion. One possible reason behind this is that the adoption of harrowing by tractor depends on the availability of tractors services, not on the mere awareness of this practice. Without a stable access to tractors, farmers cannot adopt it even if they know the advantages.

Whilst being JICA villages like group 1, we observe that group 3 did not show a significant contribution to the adoption of rice production technologies, except bund building/repairing. Even in the case of bunding, the marginal impact of 3 years diffusion is higher than the marginal impact of only one year diffusion. A possible interpretation for these observations is that, given the technology intervention, 1 year is not enough for most technologies to be learnt by other village members through within-village dissemination.

We test inter-village spillover via the comparison between group 2 and group 4. The estimation results for group 2 show that no technology in this package was successfully disseminated from JICA villages to Non-JICA villages, even after three years from the launch of project. In other words, it takes more time for inter-village spillover to exert a significant contribution to technology adoption.

In addition to these three group variables, other determinants of technology adoption are also worthy of attention. First, education level of household heads plays a significant and positive role in the adoption of dibbling and drilling; one more year of education increases the probability of practicing dibbling or drilling by 4.3%. In contrast, the impact of education is negative in the determination of bund adoption, yet its marginal effect is very small. These contrasting effects are puzzle since both are labor intensive technologies relative to other three and education usually increases opportunity cost. One possible interpretation is that bunding is a male work, while seeding tends to be a female work or rely on hired/exchange labor. Also, being 10 years younger than sample average increases bund adoption by 2.8%. Other significant determinants of technology adoption include membership of farmer association (with 9% increase probability of dibbling/drilling adoption) and operating on a clay field (with 8.6% decrease in fertilizer adoption). Better water retention of clayey fields could explain the latter.

As for the technology diffusion within villages, the result is shown at the bottom of Table 7 as the impact of group 1 when group 3 is set as the base group. From the result, we infer that, given the technology intervention, two more years for diffusion contributed a 16.3% increase in the adoption of dibbling/drilling, 18.2% increase in utilizing modern varieties, and 8.7% increase in applying fertilizers.

2) Estimation result of Probit model

Our last empirical result is Probit model for the adoption of Jasmine variety. The result shown in column (6) of Table 7 completely runs counter to a priori expectations. The probability of Jasmine adoption of group 1 is not significantly different from that of group 4. Moreover, that of group 3 is significantly lower than that of group 4.

3) Jasmine variety was officially released in 2009. It is aromatic and high-yielding at the same time. Although urban consumers prefer aromatic rice, there had been no aromatic rice widely available to Ghanaian farmers until the release of Jasmine. This special characteristics of Jasmine is the reason why we focus on it. Since there was no adopter of Jasmine before the intervention, we use a Probit model to identify the determinants of Jasmine adoption.
### Table 7 Determinants of the adoption of modern rice technologies

| Explanatory Variables | Multinomial Probit Model | Probit | (1) | (2) | (3) | (4) | (5) | (6) |
|-----------------------|--------------------------|--------|-----|-----|-----|-----|-----|-----|
| Household (HH) Level Variables | Bunding around plots | Harrowing using tractor | Dibbling or modern fertilizer | Jasmine variety |
| Household size (number) | 0.0034 | 0.0010 | 0.0059 | -0.022 | 0.0012 | -0.0259 |
| | (0.58) | (0.19) | (1.05) | (-1.53) | (0.15) | (-0.59) |
| Education of household head (years) | -0.0075** | 0.00069 | 0.0430*** | -0.0087 | 0.0032 | 0.0279 |
| | (-1.75) | (0.18) | (2.95) | (-1.12) | (0.55) | (0.87) |
| Age of households head (years) | -0.0028** | -0.0011 | -0.0002 | -0.0028 | -0.0013 | -0.0065 |
| | (-2.20) | (-1.37) | (-0.19) | (-1.39) | (-0.75) | (-0.81) |
| Adult (15-65) healthy HH labor force (number) | 0.0148 | 0.0031 | 0.0006 | 0.0309* | -0.0083 | 0.0973 |
| | (1.46) | (0.36) | (0.06) | (1.65) | (-0.62) | (1.55) |
| HH members engaged in off-farm jobs (number) | 0.0173* | -0.0009 | -0.0181 | -0.0224 | -0.0155 | 0.0849 |
| | (1.67) | (-1.0) | (-1.37) | (-1.15) | (-0.80) | (1.11) |
| Total farm size (acres) | -0.0011 | -0.0009 | -0.0009 | -0.0020 | 0.0010 | -0.0083 |
| | (-0.95) | (-0.78) | (-0.72) | (-0.78) | (0.54) | (-0.89) |
| Mean walking time from home to rice plots (min) | 0.0007 | -0.0016** | -0.0007 | 0.0001 | -0.0013 | 0.0076*** |
| | (1.45) | (-1.99) | (-0.82) | (0.08) | (-1.34) | (2.83) |
| Experience in rice farming (years) | -0.0015 | 0.0011 | 0.0005 | 0.0002 | -0.0046* | -0.0182 |
| | (-0.64) | (0.59) | (0.28) | (0.08) | (-1.80) | (-1.03) |
| Member of local farmers groups (dummy) | 0.0017 | -0.0423 | 0.0924** | 0.0594 | 0.0288 | 0.471* |
| | (0.04) | (-0.90) | (2.29) | (1.03) | (0.53) | (1.68) |
| Asset value (100,000 GHC) | 0.0135 | 0.0755 | -0.1580 | 0.0043 | 0.4190** | -0.1270 |
| | (0.36) | (0.63) | (-0.46) | (0.02) | (2.24) | (-1.25) |
| At least one plot has clay soil (dummy) | -0.0066 | -0.0498 | -0.0349 | 0.0292 | -0.0857** | -0.2960 |
| | (-0.15) | (-1.61) | (-0.85) | (0.61) | (-2.10) | (-1.32) |
| At least on plot is on sloped land (dummy) | -0.0072 | -0.0011 | -0.0396 | -0.0331 | -0.0669* | 0.2200 |
| | (-0.22) | (-0.04) | (-1.21) | (-0.58) | (-1.67) | (0.97) |

Village Level Variables

| Distance from district capital (100 km) | -0.0008* | -0.0006 | 0.0010* | -0.0009 | -0.0006 | -0.0107*** |
| | (-1.92) | (-1.40) | (2.28) | (-1.18) | (-1.28) | (-3.79) |
| Wage rate in the village (GHC/day) | 0.0152 | 0.0008 | 0.0017 | -0.0211 | -0.0116 | 0.2710*** |
| | (1.13) | (0.07) | (0.18) | (-1.14) | (-0.84) | (3.98) |
| Group 1 (dummy) | 0.1780** | 0.0740 | 0.2370*** | 0.1960*** | 0.1330*** | 0.4740 |
| | (2.17) | (1.45) | (3.66) | (3.45) | (3.11) | (1.53) |
| Group 2 (dummy) | 0.0643 | 0.0563 | 0.1280 | 0.0630 | 0.0578 | -0.1870 |
| | (1.00) | (1.50) | (1.59) | (0.70) | (1.15) | (-0.83) |
| Group 3 (dummy) | 0.1140* | 0.0116 | 0.0816 | 0.0144 | 0.0457 | -0.5750** |
| | (1.87) | (0.32) | (1.37) | (0.18) | (1.03) | (-2.05) |
| Group 1 (dummy, group 3 as the base group) | 0.0616 | 0.0624 | 0.1630*** | 0.1820*** | 0.0873** | --- |
| | (1.07) | (1.43) | (3.94) | (3.03) | (2.09) | --- |

Number of observations | 277 | 277 | 277 | 270 | 277 | 277 |

Note: Numbers are marginal effects computed at the means. z statistics are in parentheses. * p < 0.10, ** p < 0.05, *** p < 0.01. GHC stands for Ghanaian Cedi.
Particularly this negative effect is hard to interpret. However, this does not necessarily mean that JICA’s training project was not effective for or even discouraging disseminating Jasmine variety. Rather, it implies that Jasmine variety was disseminated through not only JICA’s project but also other channels. Looking at other explanatory variables, membership of farmers groups has a positive effect and distance from district capital has a negative effect. They suggest that the seed of Jasmine variety may have been distributed through groups and/or from district capital (although we do not know how it happened).

5. Conclusion

The purpose of this research is to examine if the success of Asian Green Revolution can be copied in Sub-Saharan Africa, or if modern farming technologies widely adopted during the Green Revolution can be disseminated through projects like JICA’s technology training.

By constructing a peculiar structure of samples and adopting a Multinomial Probit Model, we are able to identify within-village technology diffusion after the technology demonstration. This structure also allows us to investigate the existence of inter-village technology spillover. In addition, this study not only focuses on technology demonstration and adoption, but also emphasizes heterogeneous impacts of technology diffusions. This is the main contribution of this study.

We find that three years after the launch of intervention is enough for four technologies (bund, dibbling/drilling, modern varieties, and fertilizer) to spread and be learnt by rice producers within JICA villages, while it is hard to achieve a significant improvement of adoption rates of these technologies within one year. Moreover, we find that more than three years will be needed for inter-village technology spillover to become impactful, even if such an effect exists. In the case of Jasmine variety, JICA’s project does not seem to have an impact on farmers’ adoption of this variety. However, it may be because there are several different pathways for the dissemination of Jasmine variety.

In sum, projects like JICA’s technology training program can effectively improve farmers’ acceptance of modern rice production technologies, if enough time for technology disseminated within-villages is given. This finding supports technology training project as a means of modernization of rice production in SSA. On the other hand, it will take more time for such technologies to spillover from project villages to other villages around them. The finding has an important policy implication. Even if technology training project is effective, the number of beneficiaries will be limited and such a project will be regarded as too costly. If the package of modern rice production technology is too complicated or too invisible to assimilate, such cases will happen.

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