Adoption Pathways project discussion paper 5

February 2015

Technology diversification: Assessing impacts on crop income and agrochemical uses in Malawi

Menale Kassie[1], Hailemariam Teklewolde[2], Mot Jaleta[3], Paswel Marenya[4], Mulugetta Mekurai[5],and Olaf Erenstein[6]
[1]International Maize and Wheat Improvement Center(CIMMYT), Kenya
[2]Ethiopian Development Research Institute (EDRI), Ethiopia
[3,4]International Maize and Wheat Improvement Center(CIMMYT), Ethiopia
[5]International Maize and Wheat Improvement Center(CIMMYT), Zimbabwe
[6]International Maize and Wheat Improvement Center(CIMMYT), Mexico

Abstract

This paper estimates the on-farm impacts of adopting combination of improved agronomic practices (IAPs) on net crop income and agrochemicals use in Malawi using nationwide household survey data. A multinomial endogenous switching regression model in a counterfactual manner applied to control for selection bias stemming from both observed and unobserved heterogeneity. Results reveal that IAPs increases net crop income and reduce pesticides use (except when improved maize varieties adopted alone) and fertilizer use for non-subsidy program participants (except when improved maize varieties adopted alone). However, when improved maize varieties are combined with other IAPs, the demand for agrochemicals either reduced or kept constant. We estimate greater net crop income and larger reduction in pesticides and N fertilizer use from simultaneous adoption of IAPs, suggesting that there are complementary benefits from these practices.

JEL classification: *Q01, Q12, Q57*

Keywords: *Joint* adoption, *crop income, agrochemicals use, Malawi, multinomial switching regression*

Introduction

Agricultural productivity in most African countries is far below potential, due to poor fertility of soils, low external resource use and climate change and variability. To secure and sustain food security, agricultural systems need to be transformed to increase the productive capacity and stability of smallholder agricultural production. However, there is a question of which technologies and practices are most appropriate to reach this objective, and considerable discussion about the inadequacy of the dominant model used for intensification —relying on increased use of fertilizer, improved varieties and pesticides (Branca et al., 2011).

With expanded recognition of low agricultural productivity, environmental sustainability and climate change and variability, greater attention is now being directed towards alternative/complementary means of intensification, particularly the adoption of sustainable cropland management technologies (SCMTs). These include improved agronomic practices, integrated nutrient management, tillage and residue management, water management and agroforestry (IPCC, 2007; Branca et al., 2011, Woodfine, 2009). These technologies can be considered a strategy that can increase productivity and food security in a way that is sustainable, by addressing the degradation of ecosystem services and increasing productivity capacity, resilience and adaptation of smallholder farmers to climate variability and change (Woodfine, 2009; Branca et al., 2011; Godfray et al., 2010). Understanding the incentives for and the impediments to the adoption of these technologies is therefore a fundamental question which needs to be analyzed for designing agricultural development and ecosystems services management strategies.

Most previous research on technology adoption and impact analysis (for example, Neill and Lee, 2001; Becerril and Abdulai, 2010; Wollni et al., 2010; Kasem and Thapa, 2011; Kassie et al., 2010; 2011; Emily and Taddesse, 2013) ignored the scale effects of technologies adoption, whose adoption and economic impacts are potentially inter-related and could provide better outcomes when they are adopted jointly. Limited attention has also been given to adoption and impact analysis of improved agronomic and natural resource management practices.

In this paper, we extend a single technology analysis to multiple technology adoption and impact analysis. Specifically, we examines the impact of multiple improved agronomic practices(IAPs) on net crop income per acre[1] and on nitrogen (N) fertilizer and pesticides (herbicides + insecticides) use per acre in rural Malawi using national representative data. To achieve this objective, a multinomial endogenous switching regression in a counterfactual manner adopted to control for selection bias stemming both from observed and unobserved heterogeneity. The selection correction is based on the multinomial logit model.[2]

The IAPs examined in this study are legume-maize intercropping, legume-maize rotations and improved maize varieties. IAPs can positively change farmers' circumstances in terms of higher crop diversity per unit of land, climate change adaptation and market risk mitigation strategies, and reducing the need to purchase agrochemicals such as fertilizers and pesticides due to nitrogen fixation by legumes and biological control of weeds, diseases and pests (for example, Oswald et al. 2002; Adu-Gyamfi et al. 2007; Tilman et al., 2002; Woodfine, 2009; Branca et al., 2011)[3]. These varied outputs and degrees of resilience give farmers more options for adjusting to changes in market conditions, rainfall patterns or growing-season temperatures.

---

[1] This is net of fertilizer, seed, pesticides, and hired labor costs.

[2] A property of the multinomial logit model is the independence of irrelevant alternative (IIA) assumption. However, Bourguignon et al. (2007) showed that selection bias correction based on the multinomial logit model seems a reasonable alternative to multinomial normal models when the focus is on estimating an outcome over selected populations rather than on estimating the selection process itself. This seems true even when the IIA hypothesis is violated. Further, when combinations of technologies are exhaustive there is no other choice that farmers can make on a particular plot and thus combinations of technologies are mutually exclusive.

[3] Woodfine (2009) and Branca et al. (2011) have made a detail review on benefits (including climate change adaptation and mitigation benefits) of sustainable crop land management practices including improved agronomic practices.

Modelling multiple technology adoption impacts

In a multiple adoption framework, the adoption analysis of the three IAPs (intercropping, rotations and improved maize varieties) lead to eight(2^3) potential combinations of IAPs from which the farmer chooses (Table 1).

<Table 1 about here>

Adoption of these combinations may not be random; instead farmers may make adoption decisions based on information that is not available to the econometrician. Then, this information would affect both adoption and outcome equations, possibly generating endogeneity bias and inconsistent parameter estimates associated with unobserved heterogeneity when using standard econometric approaches (for example, least-squares estimation method). To address this problem, we model farmers' choices of combinations of IAPs and their impacts in a setting of a multinomial endogenous switching regression counterfactual framework, a relatively new selection-bias correction method based on the multinomial logit model estimated using the selmlog Stata command (Bourguignon et al., 2007). This approach allows us to get both consistent and efficient estimates of the selection process and a reasonable correction for the outcome equations, even when the assumption of the independence of irrelevant alternatives (IIA) is not achieved (Bourguignon et al., 2007). This framework has the advantage of evaluating combinations and individual practices while controlling for self-selection bias caused by both observed and unobserved heterogeneity and the interactions between choices of combinations practices (Mansur et al., 2008; Wu and Babcock, 1998). The estimation is done simultaneously in two steps. In the first stage, farmers' choices of individual and combined IAPs are modeled using a multinomial logit selection model, while recognizing the inter-relationships among them. In the second stage, the impacts of individual and combined IAPs on net crop income and agrochemicals use are evaluated using ordinary least squares (OLS) with selectivity correction terms.

Multinomial adoption selection model

Farmers are assumed to adopt IAPs that maximize their expected utility over their planning horizon. Consider the following latent model (I_{ji}^{*}) which describes the i^{th} farmer's behavior of adopting IAP combination $j (j = 1 \dots 8)$ with respect to adopting alternative IAPs combination m:

$$I_{ji}^{*} = \beta_j X_{ji} + \gamma_j \bar{X}_{ji} + \varepsilon_{ji} \qquad (1)$$

Here, X is a vector of observed exogenous variables (household, plot and location characteristics), $\bar{X}$ vector of mean value of plot-varying explanatory variables (for example, average of plot characteristics, plot distance to residence) to capture possible correlation of plot-invariant unobserved heterogeneity with observed covariates (Mundlak, 1978), β and γ are a vector of coefficient estimates for IAP combination, and ε are unobserved characteristics.

The farmer's utility from choosing a combination of IAPs is not observable but the adoption decision is observable. The farmer will choose IAPs combination j with respect to adopting any other IAPs m if:

$$I = \begin{Bmatrix} 1 \; iff \; I_{ji}^{*} > \max\limits_{m \neq 1}(I_{mi}^{*}) \text{or } \eta_{1i} < 0 \\ \vdots \\ J \; iff \; I_{ji}^{*} > \max\limits_{m \neq J}(I_{mi}^{*}) \text{or } \eta_{Ji} < 0 \end{Bmatrix} \; for \; all \; m \neq j \qquad (2)$$

Here $\eta_{ji} = \max\limits_{m \neq j}\left(I_{mi}^{*} - I_{ji}^{*}\right) < 0$ (Bourguignon et al. 2007). Equation (2) implies that the i^{th} farmer will adopt a combination of IAPs j to maximize his expected utility if it provides greater expected utility than the alternative combination $m, m \neq j$, i.e., if $\eta_{ji} = \max_{m \neq j}(I_{mi}^* - I_{ji}^*) < 0$.

Assuming that ε are identically and independently Gumbel distributed, the probability that farmer i with characteristics X will choose IAPs j can be specified by a multinomial logit model (MNL) (McFadden, 1973):

$$p_{ji} = pr(\eta_{ji} < 0|X_{ji}) = \frac{exp(\beta_j X_{ji} + \gamma_j \bar{X}_{ji})}{\sum_{m \neq 1}^{J} exp(\beta_m X_{ji} + \gamma_m \bar{X}_{ji})} \qquad (3)$$

Multinomial Endogenous Switching Treatment Regression (MESTR) Framework

In this section, we describe the implementation of the MESTR framework. The outcome equation for each possible regime j for j=1. . .8 is given as:

$$\begin{cases} Regime\ 1: Q_{1i} = \alpha_1 Z_{1i} + \delta_1 \bar{Z}_{1i} + u_{1i}\ if\ I = 1 \\ \quad \vdots \\ Regime\ J: Q_{Ji} = \alpha_J Z_{Ji} + \delta_J \bar{Z}_{Ji} + u_{Ji}\ if\ I = J \end{cases} \qquad j = 2, \dots, 8 \qquad (4)$$

Here, Q_{ji} are the outcome variables of the i^{th} farmer in regime j (j=1 refers to non-adoption group), Z represent the vector of exogenous variables influencing the outcome variables, $\bar{Z}$ mean of plot-varying explanatory variables, and the error terms (u's) are distributed with $E(u|Z,\bar{Z}) = 0$ and $Var(u|Z,\bar{Z}) = \sigma^2$. If the u's and ε's are not independent, a consistent estimation of α and δ requires inclusion of the selection correction terms of the alternative choices in (4). Bourguignon et al. (2007) show that consistent estimates of α and δ in the outcome equations (4) can be obtained by estimating the following selection bias-corrected net crop income and input use equations,

$$\begin{aligned} Regime\ 1&: Q_{1i} = \alpha_1 Z_{1i} + \delta_1 \bar{Z}_{1i} + \sigma_{1\varepsilon}\hat{\lambda}_{1i} + u_{1i}\ if\ I = 1 \\ &\vdots \\ Regime\ J&: Q_{Ji} = \alpha_J Z_{Ji} + \delta_J \bar{Z}_{Ji} + \sigma_{J\varepsilon}\hat{\lambda}_{Ji} + u_{Ji}\ if\ I = J \end{aligned} \qquad (5)$$

Here, σ_j is the covariance between ε 's and u 's, λ_j is the inverse Mills ratio derived from the estimated probabilities in (3) as follow: $\hat{\lambda}_{ji} = \sum_{m\neq j}^{J} \rho_j \left[\frac{\hat{P}_{mi} ln(\hat{P}_{mi})}{1-\hat{P}_{mi}} + ln(\hat{P}_{ji})\right]$; ρ is the correlation coefficient of ε 's and u 's and ω's are error terms with an expected value of zero. In the multinomial choice setting, there are J-1 selection correction terms, one for each alternative combination of IAPs. The standard errors in (5) are bootstrapped to account for the heteroskedasticity arising from the two-stage estimation procedures.

Lokshin and Glinskaya(2009) argue, the systems of equations (3 and 5) is identified by nonlinearities even if the vectors of observables X and Z overlap completely. Our comprehensive data would also minimize the identification problem. In the literature, however, the use of instrument is advocated to make results robust. We admit that getting a true instrumental variable is a challenge in many empirical analyses, but we excluded some explanatory variables [walking distance to input markets, number of close relatives in and outside the village, membership in a farmers' group, walking distance to an extension office, and farmers' confidence in the skills of extension workers] in income equations for identification purposes. Closer distance to input markets and extension offices, trust on extension skill and membership in farmers group may facilitate purchase of inputs such as improved varieties and the information learning and increase the probability of adoption. Close relatives may also facilitate adoption through exchange of resources either in-kind and –cash in times of critical needs. Three instruments are excluded in the fertilizer and pesticide outcome equations: if timely availability of seed is a constraint, if price of seed is a constraint and if quality of seed is a constraint. These variables may not directly influence outcome variables except via the adoption decision. The supply of seed on time and its price can constraint the integration of maize with legumes (intercropping or rotations). A simple falsification test following Di Falco and Veronesi (2011) was used to test the validity of these instruments. Results confirm that, in nearly all cases, these variables are jointly significant in the adoption equations but not in the outcome regression equations. A simple correlation analysis between instruments and outcome variables also shows that there is insignificant correlation.

Counterfactual analysis and adoption effects estimation

Following Carter and Milon (2005), Di Falco and Veronesi (2011) and the impact literature (Heckman et al., 2001), equation (5) is used to derive the adoption effect by generating the counterfactual crop income and agrochemicals use distribution using the following expected conditional outcomes.

Adopters with adoption (actual): $E\left(Q_{ji}\middle|I=j,Z_{ji},\bar{Z}_{ji},\hat{\lambda}_{ji}\right)=\alpha_j Z_{ji}+\delta_j\bar{Z}_{ji}+\sigma_{j\varepsilon}\hat{\lambda}_{ji}$ (6)

Non-adopters without adoption (actual)

: $E\left(Q_{1i}\middle|I=1,Z_{1i},\bar{Z}_{1i},\hat{\lambda}_{1i}\right)=\alpha_1 Z_{1i}+\delta_1\bar{Z}_{1i}+\sigma_{1\varepsilon}\hat{\lambda}_{1i}$ (7)

Adopters had they decided not to adopt (counterfactual): $E\left(Q_{1i}\middle|I=j,Z_{ji},\bar{Z}_{ji},\hat{\lambda}_{ji}\right)=\alpha_1 Z_{ji}+\delta_1\bar{Z}_{ji}+\sigma_{1\varepsilon}\hat{\lambda}_{ji}$ (8)

Non-adopters had they decided to adopt (counterfactual): $E\left(Q_{ji}\middle|I=1,Z_{1i},\bar{Z}_{1i},\hat{\lambda}_{1i}\right)=\alpha_j Z_{1i}+\delta_j\bar{Z}_{1i}+\sigma_{j\varepsilon}\hat{\lambda}_{1i}$ (9)

The actual expected outcomes of adopters observed from the data. After estimating the parameters of equation (5) the following conditional expectations for each outcome variable computed in the actual and counterfactual cases:

Equations 6 and 7 are the actual adopters and non-adopters expected outcomes observed in the data, respectively. Equations 8 and 9 represent the "counterfactual" expected outcomes for adopters and non-adopters, respectively. The counterfactual is defined as what the crop income/agrochemicals use of adopters would have been if the returns on their characteristics/covariates had been the same as the returns on the characteristics of the non-adopters, and vice versa.

These conditional expectations allow us to calculate the average adoption effects on adopters (ATT) and on the non-adopters (ATU). The difference of the actual outcomes of adopters (equation 6) and their counterfactual mean outcomes (equation 8)gives the ATT defined below:

$$ATT = E\left(Q_{ji}\middle|I = j, Z_{ji}, \bar{Z}_{ji}, \hat{\lambda}_{ji}\right) - E\left(Q_{1i}\middle|I = j, Z_{ji}, \bar{Z}_{ji}, \hat{\lambda}_{ji}\right) = Z_{ji}\left[\alpha_j - \alpha_1\right] + \bar{Z}_{ji}\left[\delta_j - \delta_1\right] + \lambda_{ji}\left[\sigma_j - \sigma_1\right] \qquad (10)$$

Similarly, the ATU is defined as the difference of the counterfactual mean outcomes of non-adopters (equation 9) and their actual outcomes (equation 7):

$$ATU = E\left(Q_{ji}\middle|I = 1, Z_{1i}, \bar{Z}_{1i}, \hat{\lambda}_{1i}\right) - E\left(Q_{1i}\middle|I = 1, Z_{1i}, Z_{1i}, \bar{Z}_{1i}, \hat{\lambda}_{1i}\right) = Z_{1i}\left[\alpha_j - \alpha_1\right] + \bar{Z}_{1i}\left[\delta_j - \delta_1\right] + \lambda_{1i}\left[\sigma_j - \sigma_1\right] \qquad (11)$$

The first terms on the right-hand side of equations (10) and (11) represent the expected change in Q due to the adoption of combination of IAPs j conditional on observed choices and returns to characteristics. The second terms adjust the adoption effects stemming from unobserved characteristics.

Study areas and sampling procedure

We use the data collected during March-June 2011 by the International Maize and Wheat Improvement Center (CIMMYT) in collaboration with the Department of Agricultural Research Services (DARS) of Malawi. The sample contains a total of 1,925 farm households operating on 2,922 maize plots. Maize is the principal food crop in Malawi, covering over 90% of the production area allocated to cereals and cereal production. The crop is almost exclusively produced by smallholders, and it is estimated that amongst these farmers 97% cultivate maize (Gilbert et al. 2013). The country's food security is defined in terms of adequate availability of, and access to, maize and while per capita maize consumption in Malawi is among the highest in Africa at 150 kg per year (Gilbert et al. 2013).

A multistage sampling procedure was employed to select villages from each district and households from each village. First, based on their maize production potential, sixteen districts from the three regions (North, Central and South) of Malawi were selected. Second, based on proportionate random sampling, the following selection was made: 3-16 Extension Planning Areas (EPAs) in each district, 1-7 sections in each EPA, 1-5 villages in each section, and 2-8 farm households in each village. The survey covers a total of 118 EPAs, 201 sections and 397 villages.

Data Description and Empirical Specification

Table 1 presents the proportions of plots under the different combination of IAPs and modern variety. Of the 2,922 plots, about 19% did not use any of the IAPs, while all types of practices were jointly adopted on about 5% of the plots. Maize is often rotated and intercropped with legumes such as pigeonpea, groundnuts, and cowpea. The sample unconditional and conditional probabilities presented in Table 2 highlight the existence of interdependence across the IAPs. The unconditional statistics show that maize-legume rotation, maize-legume intercropping and improved maize varieties is practiced on about 43, 21 and 55% of the plots, respectively. However, the probability of adoption of rotations decreases from 21% to 18% conditional on adoption of intercropping. Similarly, the conditional probability of a household adopting intercropping decreases from 43% to 37% when farmers adopt rotations. All of these results are significant at the 1% level. These results indicate substitutability between adoption of intercropping and rotation. Adoption of improved maize varieties increases by 4% conditional on adoption of intercropping and rotations, showing the complementarity of varieties and these practices.

<Table 2 about here>

Table 3 presents the description and summary statistics of the control variables used in the empirical analysis for the full sample and the eight sub-groups. The specification of our empirical model is based on a review of theoretical work and previous similar empirical adoption and impact studies on integrated natural resource management and sustainable land management practices (for example, Neill and Lee, 2001; Arellanes and Lee, 2003; Lee, 2005; Knowler and Bradshaw, 2007; Ricker-Gilbert and Jayne, 2009; Bellon and Hellin 2010; Wollni et al., 2010; Kasem and Thapa, 2011; Kassie et al. 2015). The detailed description and hypothesis of these variables are available in Kassie et al. (2015).

<Table 3 about here>

Econometric results and discussion

Impact of IAPs on crop income and agrochemicals use

For the sake of space, the regression results of the outcome and adoption equations are not discussed but presented in Appendix Tables A1-A4. However, it is worth mentioning that there are differences between the outcome equations coefficients among the different IAPs adopter groups. This illustrates the heterogeneity in the sample with respect to crop net income and demand for N and pesticides. It is also worth noting that, given our data, many of the coefficients on the selection correction terms are significant, suggesting that adoption of different combination of IAPs will not have the same effects on non-adopters, should they choose to adopt, as it would on adopters.

The estimates of the unconditional and conditional effects of adoption of IAPs on net crop income, N fertilizer and pesticides use are presented in Tables 4 and 5, respectively. The unconditional effects (Table 4) indicate that adopters of any combinations of the IAPs earn more crop income and use more N fertilizer, on average, than non-adopters. The opposite is true for pesticide application, where non-adopters use less pesticide, on average, than adopters. However, this simple comparison of the actual outcomes is misleading because the comparison is not based on the same observed and unobserved characteristics that may have influence on outcome variables. The difference in net crop income and inputs use may be caused by observed and unobserved characteristics of the farm households such as their skills and motivation. This problem can be addressed by estimating the counterfactual outcomes using equations (8 and 9) and comparing these outcomes with the estimated actual expected outcomes.

<Tables 4-5 about here>

Columns C, F and I present the conditional impact of adoption of various combinations of IAPs on crop income, pesticides and N fertilizer use, computed as the difference between columns A and B, D and E, and G and H, respectively (Table 5). Results show that the adoption of either individual IAP or a combination of them provides higher net crop income compared with non-adoption. However, the largest income (14 thousands MK/acre) is obtained from adoption of improved maize varieties in combination with both intercropping and rotations practices ($I_1R_1V_1$). In all counterfactual cases, had the adopters did not adopt IAPs, they would have earned less income (see column B of adopters row). Similarly, under the counterfactual conditions that non-adopters had adopted, these households would have earned more if they had adopted (see column A of non-adopters row). Again, the highest payoff (28 thousands MK/acre) is achieved from joint adoption of IAPs.

On agrochemical use, the analysis shows that the adoption of improved maize varieties significantly increased the application of pesticides. This is probably because farmers would like to avoid risk, as high yielding varieties may be susceptible to pest outbreaks. However, this effect is reduced when improved maize varieties adopted jointly with other practices. Results reveal that the adoption of intercropping or rotations with or without improved maize varieties either keeps constant or significantly reduce the average pesticide application of adopters and non-adopters, if they did adopt. Adopters would have applied more pesticides (except in the adoption of improved maize varieties scenario), if they did not adopt (see column E of the adopters row), whereas non-adopters would have used less if they did adopt except in the adoption of improved maize varieties alone (see column D of non-adopters row). These results imply that IAPs, particularly intercropping and rotations save farmers from using pesticides by controlling diseases and pest and weed infestation. These practices therefore can be considered as production cost saving, risk management and environmental safeguard strategies.

As for fertilizer use, we found that, for farmers who adopted combination of IAPs that contains improved maize varieties ($I_0R_0V_1$), the nitrogen (N) application is significantly higher than it would have been if the adopters had not adopted ($I_0R_0V_0$). This is probably due to the complementarity between improved maize varieties adoption and fertilizer. However, contrary to our expectation, the demand for N fertilizer increases with adoption of intercropping and rotations with or without improved maize varieties. Similarly, if non-adopters did adopt IAPs, the mean effect would also be an increase in N application. These results are not consistent with the ecological role of IAPs, such as reducing nitrogen application because of biological nitrogen fixation via legumes, or with previous empirical studies, such as those of Wu and Babcock (1998) and Teklewold et al., (2013), who found in the Central Nebraska basin and Ethiopia, respectively, that farmers either reduce or keeps constant application of nitrogen fertilizer due to the adoption of IAPs and minimum tillage. In this regard, our results suggest that IAPs do not benefit farmers in reducing their production costs, and also do not bestow environmental benefits, as nitrogen application increases with IAPs.

This result seems to be confounded with the inputs subsidy program of Malawi. Though subsidy may help in increasing technology uptake, if it is not used properly it might reduce the value of the product, in our case fertilizer, as the program provides fertilizer almost freely.[4,5] To investigate whether our results are due to the subsidy program, we run a separate nitrogen demand regression for fertilizer subsidy program participants and non-participants.[6]

---

[4] The price of subsidized fertilizer for the 2010/11 crop calendar was USD 3.3 per 50 kg both for NPK and urea, while the actual market price was USD 36 and 32 per 50 kg, respectively, for NPK and urea.

We find two contrasting results.[7] Both the unconditional and conditional average effects results Tables 6 and 7 respectively show that subsidized farmers' fertilizer consumption increased with adoption of either of intercropping or rotations with or without improved maize varieties. However, the demand for N fertilizer is lower for non-subsidized farmers with the adoption of IAPs (except when they adopt improved maize varieties alone). The non-subsidized farmers seemed to properly credit the N fixed due to adoption of these practices and hence significantly reduced farm level use of fertilizer even when there is adoption of improved seeds. Higher N fertilizer application while using IAPs may be justifiable as long as the marginal return per unit of application is higher than without application. However, this is not the case in our sample. Though an in-depth multivariate

---

[5] See Dorward and Chirwa (2009), Ricker-Gilbert and Jayne (2009), and Holden and Lunduka (2012) for more detailed information about Malawi's input subsidy program.

[6] Access to subsidy may not be random, as the subsidy administrators may use selection criterion that are not observable to us in addition to observable criteria. Though getting a valid instrument is empirically challenging, we use the *number of years the household has lived in the village* and *whether the household has connections with local administrators and agricultural officials* as potential instrumental variables. These two variables capture the social capital at an individual and village level that may influence access to subsidy by farmers. In addition to these variables, other variables (family size, age and sex of household head, etc.,) that affect access to subsidy are included in the fertilizer demand equations. The number of years the household has lived in the village is used as an instrument by Ricker-Gilbert and Jayne (2009), and sex and age used are by Holden and Lunduka (2012), as the subsidy program targeted female-headed households and households with many dependents (Holden and Lunduka, 2012; Ricker-Gilbert and Jayne, 2009). We follow a two-step residual inclusion test of endogneity. First, we estimate and obtain the residual from the probit regression of subsidy. Second, the estimated residual along with subsidy variable is included in the fertilizer demand regression. Our results indicate that the instruments have a jointly significant effect on fertilizer subsidy variable (at the 5% statistical level). A significance test on the coefficient of the residuals shows that endogenity is not a problem. The result is available on request.

[7] To save space, the regression results are not reported, but available on request.

analysis may be required, a simple t-test on net crop income distribution showed that almost there is no significant difference in mean net crop income between the two groups of farmers across the different practices (Table 8)[8], suggesting that supplementary policies that lead to an efficient use of scarce resources such as inorganic fertilizer is important.

<Tables 6-7 about here>

< Table 8 about here>

Concluding remarks

Increasing and sustaining food production while improving or maintaining a healthy agro-ecosystem is a challenge in many African countries. Sustainable cropland management practices aim to enhance the productivity and resilience of agricultural production systems while conserving the natural resource base. Thus understanding the incentives for and the impediments to the adoption of these practices is a fundamental question which needs to be analyzed for designing agricultural development and ecosystems services management strategies. The objective of this paper is to improve our understanding of the impacts of adoption of improved agronomic practices (IAPs) on crop income and agrochemicals use using nationally-representative, comprehensive household-plot level data in rural Malawi. We developed a multinomial endogenous switching regression methodology in a counterfactual framework, where selectivity is modeled as a multinomial logit model (as opposed to univariate probit as in the Heckman model). It applies the two-step method proposed by Bourguignon et al. (2007). The estimated coefficients are used to identify how crop income and inputs use respond to adoption of IAPs.

[8] It does not seem there is a leakage problem as the average application of fertilizer is higher for subsidized farmers (50 Kg N/ha and 31 Kg P/ha) than non-subsidized farmers (43 Kg N/ha and 28 Kg P/ha).

The empirical results indicated that the adoption of IAPs either individually or in combination has a win-win effect in terms of increasing crop income and downsizing the use of pesticides (expect when improved maize varieties adopted alone) and N fertilizer use for non-fertilizer subsidy participants. In this regard, intercropping and rotations have positive economic and environmental effects, through reducing external off-farm inputs without significantly affecting crop income. However, the estimation results suggest that fertilizer application behavior following the adoption of IAPs differs between subsidized and non-subsidized farmers. There is a negative and significant association between fertilizer use and adoption of IAPs for farmers not participating in a fertilizer subsidy program, and a positive and significant association for those participating.

Another interesting result of this study is that farmers in the study areas would benefit the most in terms of increasing their crop income as well as reducing the demand for pesticides use and Nitrogen fertilizer (for non-fertilizer subsidized farmers) from the joint adoption of IAPs . These findings will inform policy makers and development practitioners in the design of effective sustainable intensification interventions to combat food insecurity and poverty and environmental degradation. Fertilizer subsidy weakens the ecological role of IAPs calling for a policy to harmonize the integration of agricultural productivity enhancing inputs and practices. It also suggests that providing extension advice for farmers on the benefit of IAPs may be important for efficient use of scarce and expensive resources, such as fertilizer.

Finally, the results of this study are based on repeated cross-sectional plot-level data which may not fully capture the dynamics of adoption as relating to crop income and input use. Future analysis using panel data may be needed to examine the relationship between the adoption of IAPs and crop income and input use, in order to control for unobserved heterogeneity, to provide more robust evidence on the implication of IAPs for agriculture and the environment, and to see whether the results persist over time.

References

Arellanes P. and D. R. Lee. 2003. The Determinants of Adoption of Sustainable Agriculture Technologies, Paper presented at XXV Conference of International Association of Agricultural Economists (Durban, South Africa, August 2003).

Becerril, J., and A. Abdulai. 2010. The Impact of Improved Maize Varieties on Poverty in Mexico: A Propensity Score Matching Approach. *World Dev.* 38(7):1024–1035.

Bellon, M.R., Hellin J. 2010. Planting hybrids, keeping landraces: agricultural modernization and tradition among small-scale maize farmers in Chiapas, Mexico. *World Deve.* 39 (8), 1434-1443.

Bourguignon, F., M. Fournier, and M. Gurgand. 2007. Selection Bias Corrections Based on the Multinomial Logit Model: Monte-Carlo Comparisons. *J. Econ. Surveys* 21:174-205.

Branca, G.,McCarthy, N., Lipper, L. and Jolejole, M., C. (2011) Climate-Smart Agriculture: A Synthesis of Empirical Evidence of Food Security and Mitigation Benefits from Improved Cropland Management. Food and Agriculture Organization of the United Nations (FAO). Rome, Italy.

Carter, D.W., and J.W. Milon. 2005. Price Knowledge in Household Demand for Utility Services. *Land Economics* 81:265-283.

Di Falco, S., and Veronesi, M. ‘On adaptation to climate change and risk exposure in the Nile basin of Ethiopia’ (IED working paper 15, ETH Zurich, March 2011).

Dorward, A., and E. Chirwa. 2009. The Agricultural Input Subsidy Program 2005 to 2008: Further Analysis. ODI Mimeograph.

Gilbert, R.A., Sakala, W.D., and Benson, T. (2013) Gender analysis of a nationwide cropping system trial survey in Malawi. African Studies Quarterly. The Online Journal of for African Studis. http://www.africa.ufl.edu/asq/v6/v6i1a9.htm.

Godfray H. C, J.R. Beddington, I.R. Crute, L.Haddad, D.Lawrence, J.F Muir, J.Pretty, S. Robinson, S.M. Thomas, C. Toulmin. 2010. Food Security: The Challenge of Feeding 9 Billion People. Science. 327: 812-818.

Heckman, J. J., Tobias, J. L., and Vytlacil, E. J. 'Four Parameters of Interest in the Evaluation of Social Programs', *Southern Economic Journal*, Vol. 68, (2001) pp. 210–233.

Holden, S., and R. Lunduka. 2012. Do Fertilizer Subsidies Crowd Out Organic Manures? The Case of Malawi. *Agric. Econ.* 43,303-314

Jhamtani, H. 2011. The Green Revolution in Asia: Lessons for Africa. In *Climate Change and Food Systems Resilience in Sub-Saharan Africa*. FAO, Rome.

Kasem, S., and G.B. Thapa. 2011. Crop Diversification in Thailand: Status, Determinants, and Effects on Income and Use of Inputs. *Land Use Policy* 28:618-628.

Kassie, M., Hailemariam, T, Moti, J., Marenya, P. and Erenstein, O. 2015. Understanding the adoption of a portfolio of sustainable intensification practices in eastern and southern Africa. Land use Policy, 42: 400-411

Kassie, M., B. Shiferaw, and M. Geoffrey. 2011. Agricultural Technology, Crop Income, and Poverty Alleviation in Uganda. *World Development* 39:1784-1795.

Kassie, M., P. Zikhali, J. Pender, and G. Kohlin. 2010. The Economics of Sustainable Land Management Practices in the Ethiopian Highlands. *Journal of Agricultural Economics* 61:605-627.

Knowler, D., and B. Bradshaw. 2007. Farmers' Adoption of Conservation Agriculture: A Review and Synthesis of Recent Research. *Food Policy* 32:25-48.

Lokshin, M. and Sajaia, Z., 2011. Impact of interventions on discrete outcomes: Maximum likelihood estimation of the binary choice models with binary endogenous regressors. The Stata Journal, 11(3):368–385.

Mansur, E.T., R. Mendelsohn, and W. Morrison. 2008. Climate Change Adaptation: A Study of Fuel Choice and Consumption in the US Energy Sector. *Journal of Environmental Economics and Management* 55:175-193.

McFadden, D. 1973. Conditional Logit Analysis of Qualitative Choice Behavior. In P. Zarembka ed. *Frontiers in Econometrics*. Academic Press.

Neill, S.P., and D.R. Lee. 2001. Explaining the Adoption and Dis-adoption of Sustainable Agriculture: The Case of Cover Crops in Northern Honduras Economic Development and Cultural Change 49: 793–820.

Oswald, A., Ransom, J. ., Kroschel, J., & Sauerborn, J. 2002. Intercropping controls Striga in maize based farming systems. Crop Protection, 21(5), 367-374.

Ricker-Gilbert, J., and T.S. Jayne. 2009. Do Fertilizer Subsidies Affect the Demand for Commercial Fertilizer? An Example from Malawi." Contributed Paper presented at the International Association of Agricultural Economists Conference, Beijing, China. 16th–22nd August.

Teklewold H., Kassie M., Shiferaw B. and Köhlin G. 2013. Cropping systems diversification, conservation tillage and modern seed adoption in Ethiopia: Impacts on household income, agro-chemical use and demand for labor. Ecological Economics, 93: 85-93.

Tilman, D., K.G. Cassman, P.A. Matson, R. Naylor, and S. Polasky. 2002. "Agricultural Sustainability and Intensive Production Practices." *Nature* 418:671-677.

Woodfine, A. 2009. "Using Sustainable Land Management Practices to Adapt to and Mitigate Climate Change in Sub-Saharan Africa." Resource guide version 1. http://www.caadp.net/pdf/Using%20SLM%20 Practices%20to%20Adapt%20and%20Mitigate%20Climate%20Change.pdf

Wollni, M., D.R.Lee, and L.T.Janice. 2010. Conservation Agriculture, Organic Marketing, and Collective Action in the Honduran Hillsides. Agricultural Economics 41: 373–384.

Wu, J.J., and B.A. Babcock. 1998. The Choice of Tillage, Rotation, and Soil Testing Practices: Economic and Environmental Implications. *American Journal of Agricultural Economics* 80:494-511.

Table 1. Alternative combinations of Improved agronomic practices(IAPs) on maize plots

Choice (j)	Improved agronomic practices	Maize-legume intercropping (I)		Legume-Maize rotation (R)		Improved maize varieties (V)		Frequency (%)
		S_1	S_0	T_1	T_0	V_1	V_0	
1	$I_0R_0V_0$		√		√		√	19.44
2	$I_1R_0V_0$	√			√		√	16.43
3	$I_0R_1V_0$		√	√			√	5.68
4	$I_0R_0V_1$		√		√	√		24.71
5	$I_1R_1V_0$	√		√			√	3.15
6	$I_1R_0V_1$	√			√	√		18.89
7	$I_0R_1V_1$		√	√		√		7.19
8	$I_1R_1V_1$	√		√		√		4.52

Note: The binary triplet represents the possible IAPs combinations. Each element in the triplet is a binary variable for a SIP: Legume-maize Intercropping (I), Legume-maize rotations (T) and modern seed (V). Subscript 1 = adoption and 0 = otherwise.

Table 2. The unconditional and conditional probabilities of adoption of IAPs (%)

	Maize-legume intercropping (I)	Legume-Maize rotation (R)	Improved maize varieties (V)
$P(Y_k = 1)$	42.9	20.5	55.3
$P(Y_k = 1\|Y_I= 1)$	100.0	17.8***	54.5
$P(Y_k = 1\|Y_R = 1)$	37.3***	100.0	57.0
$P(Y_k = 1\|Y_V = 1)$	42.3	21.2	100.0
$P(Y_k = 1\|Y_R = 1, Y_V = 1)$	38.6**	100.0	100.0
$P(Y_k = 1\|Y_I = 1, Y_V = 1)$	100.0	19.3	100.0
$P(Y_k = 1\|Y_I= 1, Y_R = 1)$	100.0	100.0	58.9*

Note: Y_k is a binary variable representing the adoption status with respect to choice *k* (*k* = Maize-legume intercropping (I), maize-legume rotation (R) or Improved maize varieties (V)); *, ** and *** indicate a statistically significant difference at 10, 5 and 1%, respectively.

Table 3. Definitions and summary statistics (mean values) of the variables used in the analysis

Variable	Description	Mean values for IAPs combination								Mean of all IAPs	Sd
		$I_0R_0V_0$	$I_1R_0V_0$	$I_0R_1V_0$	$I_0R_0V_1$	$I_1I_1V_0$	$I_1R_0V_1$	$I_0I_1V_1$	$I_1R_1V_1$		
	Outcome Variables										
Netincome	Net crop income (‘000 MK/acre)	45.89	47.61	54.37	48.16	51.89	49.56	48.78	50.02	48.49	42.91
N	Nitrogen fertilizer (Kg/acre)	16.90	18.40	24.57	17.87	23.76	19.38	29.63	26.49	19.89	17.03
Pesticide	Pesticide (Lit./acre)	0.85	0.06	0.12	1.48	0.11	0.13	0.10	0.10	0.14	0.99
	Household characterstics										
Gender	Sex of the head (1=if male)	0.88	0.78***	0.83	0.85	0.80**	0.82***	0.86	0.78*	0.83	-
Age	Age of the head, yrs	42.40	41.79	43.72	41.57	44.49	41.75	44.05*	43.25	42.27	14.28
Educhead	Husband education, yrs	5.63	5.74	5.45	5.96**	5.30	5.96**	6.00	5.15*	5.78	3.73
Educspous	Spouse education, yrs	3.81	3.53*	3.96	4.05*	3.57	3.90	4.28**	3.64	3.87	3.58
Famlysize	Family size	5.20	5.06	5.09	5.36*	5.70**	5.20	5.03	5.28	5.22	2.17
	Resource constraints										
Farmsize	Farm size, acres	3.53	3.05***	3.48	3.93**	3.52	2.92***	3.79*	2.77***	3.41	3.22
Tlu	Livestock size	3.06	1.03**	0.75**	2.69	0.90**	3.23	3.13	0.65**	2.37	25.77
Credtconst	1=if credit is a constraint (credit is needed but unable to get)	0.68	0.72	0.70	0.67	0.66	0.70	0.66	0.73	0.68	.
Fertsubsidy	1=if household get fertilizer subsidy	0.73	0.77	0.69	0.76	0.79	0.85***	0.79	0.86***	0.78	.
	Market access										
Mktinputdist	Walking distance to input markets, min.	5.42	5.85	5.88	5.24	12.42**	7.34**	3.88**	10.64**	6.18	17.43
Mktoutdist	Walking distance to output markets. min.	43.67	41.69	42.55	41.16	42.23	39.26	39.41	36.49	41.15	31.06
Timeseed	1=if timely availability of seed is constraint	0.35	0.35	0.40	0.45***	0.42	0.45***	0.41**	0.42	0.40	.-
Priceseed	1=if seed price is a constraint	0.46	0.50	0.54*	0.54**	0.48	0.57***	0.56***	0.62***	0.53	.-
Qualtyseed	1=if seed quality is a constraint	0.31	0.30	0.41**	0.35*	0.36	0.43***	0.48***	0.44***	0.37	.-
	Social capital network and extension										
Trader	Number of grain traders that farmers know	8.54	9.20	9.89**	8.66	10.61**	9.22	10.11**	9.87*	9.12	9.14
Kinship	Number of close relatives	6.29	6.51	6.80	6.33	8.82***	6.72*	6.78	6.89	6.59	5.73
Group	1=if member of rural institutions	0.53	0.57	0.49	0.61**	0.63	0.54	0.49	0.54	0.56	0.79
Distext	Walking distance to extension office, min	15.06	11.63	13.63	13.46	11.71	18.63	23.07*	18.82	15.33	85.61
Extenskill	1=if confident with skill of extension workers	0.76	0.75	0.78	0.75	0.76	0.74	0.80	0.75	0.76	.-
	Shocks										
Rainfalindex	Rainfall index (1= best)	0.64	0.63	0.67*	0.62**	0.56***	0.59***	0.67*	0.53***	0.62	0.26
Pestsdisease	1=if pest and disease	0.18	0.21	0.18	0.18	0.15	0.20	0.19	0.14	0.19	.-

Variable	Description	Mean values for IAPs combination								Mean of all IAPs	Sd
		$I_0R_0V_0$	$I_1R_0V_0$	$I_0R_1V_0$	$I_0R_0V_1$	$I_1I_1V_0$	$I_1R_0V_1$	$I_0I_1V_1$	$I_1R_1V_1$		
	Plot characterstics										
Plotdist	Plot distance from home, minutes	19.48	20.86	19.11	20.13	18.57	19.64	20.29	16.98	19.79	23.78
Tenure	1=if own plot	0.96	0.96	0.95	0.96	0.97	0.97	0.93*	0.94	0.96	-
Womnmangr[b]	1=if women managed plot	0.23	0.17***	0.15**	0.20	0.16	0.15***	0.21	0.14*	0.19	-
Menmangr[b]	1=if men managed plot	0.58	0.51**	0.62	0.61	0.55	0.59	0.56	0.53	0.58	-
Goodsoilplt[c]	1=if good soil quality plot	0.49	0.44	0.51	0.50	0.51	0.44	0.44	0.44	0.47	-
Medmsolplt[c]	1=if medium soil quality plot	0.40	0.42	0.31**	0.38	0.36	0.42	0.38	0.36	0.39	-
Flatslop[d]	1=if flat slope plot	0.72	0.55***	0.68	0.62***	0.59***	0.54***	0.68	0.45***	0.61	-
Medumslop[d]	1=if medium slope plot	0.20	0.30***	0.21	0.27***	0.27*	0.32***	0.24	0.38***	0.27	-
Shalwdepth[e]	1=if shallow depth of soil	0.17	0.21	0.13	0.14	0.29**	0.22	0.11	0.25	0.18	-
Medmdepth[e]	1=if medium depth of soil	0.40	0.43	0.32	0.41	0.32	0.42	0.37	0.36	0.40	-
Manureuse	1=if use manure	0.23	0.34***	0.27	0.27	0.27	0.33***	0.22	0.27	0.28	-
Location variables											
mzimba	1=if Mzimba district	0.148	0.077	0.114	0.114	0.043	0.051	0.086	0.045	0.095	
denza	1=if Denza district	0.046	0.133	0.018	0.035	0.076	0.085	0.019	0.045	0.062	
kasungu	1=if Kasungu district	0.081	0.006	0.078	0.083	0.033	0.014	0.162	0.045	0.059	
ntcheu	1=if Ntcheu district	0.060	0.106	0.048	0.054	0.043	0.063	0.024	0.045	0.062	
dowa	1=if Dowa district	0.085	0.023	0.084	0.072	0.000	0.038	0.071	0.023	0.056	
ntchisi	1=if Ntchisi district	0.030	0.006	0.012	0.032	0.033	0.025	0.029	0.015	0.024	
salima	1=if Salima district	0.063	0.008	0.127	0.066	0.033	0.002	0.090	0.015	0.046	
mchinji	1=if Mchinji district	0.065	0.004	0.072	0.048	0.033	0.005	0.071	0.023	0.038	
balaka	1=if Balaka district	0.069	0.031	0.108	0.101	0.239	0.049	0.062	0.258	0.082	
blantyre	1=if Blantyre district	0.021	0.067	0.000	0.022	0.000	0.080	0.029	0.053	0.040	
chiradzulu	1=if Chiradzulu district	0.005	0.094	0.000	0.012	0.011	0.067	0.010	0.030	0.035	
machiga	1=if Machiga district	0.025	0.090	0.012	0.042	0.130	0.114	0.052	0.235	0.070	
mangochi	1=if Mangochi district	0.049	0.125	0.048	0.060	0.120	0.100	0.062	0.045	0.077	
mwanza	1=if Mwanza district	0.007	0.033	0.000	0.010	0.033	0.045	0.010	0.030	0.021	
thyolo	1=if Thyolo district	0.019	0.108	0.006	0.030	0.033	0.168	0.000	0.030	0.064	

Variable	Description	Mean values for IAPs combination								Mean of all IAPs	Sd
		$I_0R_0V_0$	$I_1R_0V_0$	$I_0R_1V_0$	$I_0R_0V_1$	$I_1I_1V_0$	$I_1R_0V_1$	$I_0I_1V_1$	$I_1R_1V_1$		
N	Number of observations	568	480	166	722	92	552	210	132	2922	

Note: Numbers in parentheses are standard deviation; [a] 1 MK = 0.0025 USD at the time of survey; [b]plots managed by both are reference category; [c]plots with poor soil quality are reference category; [d]plots with steep slope are reference category; [e]plots with deep soil depth are reference category.; Lilongwe is a reference group for districts.

Table 4. The unconditional average effect of adoption of IAPs

IAPs combination	Net crop income		N fertilizer application		Pesticides application	
	Net crop income ('000 MK/acre)	Adoption effects	N (kg/acre)	Adoption effects	Pesticide (Lit./acre)	Adoption effects
$I_0R_0V_0$	42.19 (0.31)	-	16.89 (0.56)	-	0.85 (0.15)	-
$I_1R_0V_0$	49.56 (0.42)	7.36 (0.52)***	27.59 (1.06)	10.69 (1.16)***	0.06 (0.02)	-0.79 (0. 08)***
$I_0R_1V_0$	49.99 (0.69)	7.79 (0.75)***	24.57 (1.98)	7.66 (1.57)***	0.12 (0.10)	-0.67 (0.12)***
$I_0R_0V_1$	45.73 (0.33)	3.53 (0.45)***	35.74 (1.08)	18.84 (1.33)***	1.48 (0.31)	0.62 (0.39)**
$I_1R_1V_0$	61.61 (1.01)	19.41 (1.06)***	23.76 (2.42)	6.86 (1.68)***	0.11 (0.05)	-0.74 (0.13)***
$I_1R_0V_1$	51.23 (0.39)	9.03 (0.49)***	19.37 (0.61)	2.48 (0.83)***	0.13 (0.06)	-0.72 (0.26)***
$I_0R_1V_1$	60.71 (1.07)	18.51 (1.11)***	29.63 (1.99)	12.73 (1.53)***	0.10 (0.04)	-0.75 (0.12)***
$I_1R_1V_1$	61.86 (2.02)	19.66 (2.05)***	26.49 (2.17)	9.59 (1.55)***	0.09 (0.04	-0.76 (0.11)***

Note: figures in parentheses are standard errors; *, ** and *** indicate statistical significance at 10%, 5% and 1% level.

Table 5. Impact of combinations of IAPs on expected net crop income, Nitrogen (N) fertilizer and pesticide application (conditional impact)

Sample	Outcome	Net crop income ('000 MK/acre)			Pesticide application (Lit./acre)			N application (Kg/acre)		
		Adoption status		Adoption Effects	Adoption status		Adoption Effects	Adoption status		Adoption Effects
		Adopting (j= 2,. . .,8)	Non-Adopting (j=1)		Adopting (j= 2,. . .,8)	Non- Adopting (j=1)		Adopter (j= 2,...,8)	Non-Adopting (j=1)	
		A	B	C	D	E	F	G	H	I
Adopter	$E(Q_j \mid I=2)$	47.80 (0.87)	38.09 (0.86)	9.71 (1.23)***	0.26 (0.03)	1.28 (0.63)	-1.01 (0. 63)**	18.22 (0.28)	13.43 (0.32)	4.79 (0.42)***
	$E(Q_j \mid I=3)$	54.36 (2.13)	45.93 (1.25)	8.44 (2.47)***	0.02 (0.01)	0.86 (1.06)	-0.83 (1.05)	23.78 (1.24)	17.21 (0.48)	6.57 (1.33)***
	$E(Q_j \mid I=4)$	49.03 (0.57)	38.61 (0.42)	10.42 (2.22)***	1.86 (0.22)	0.36 (0.56)	1.50 (0.60)***	24.68 (0.21)	16.29 (0.27)	8.38 (0.34)***
	$E(Q_j \mid I=5)$	51.89 (3.92)	40.04 (1.78)	11.84 (4.31)***	0.11 (0.05)	1.88 (1.60)	-1.78 (0.68)***	22.35 (2.51)	22.35 (0.78)	6.71 (2.63)***
	$E(Q_j \mid I=6)$	49.65 (0.78)	38.29 (0.67)	11.37 (1.03)***	0.13 (0.03)	1.66 (0.77)	-1.53 (0.77)**	19.31 (0.25)	13.66 (0.35)	5.65 (0.42)***
	$E(Q_j \mid I=7)$	54.39 (2.09)	41.85 (0.87)	12.54 (2.26)***	0.10 (0.02)	1.10 (1.67)	-0.99 (1.67)	29.05 (1.15)	17.43 (0.53)	11.61 (1.27)***
	$E(Q_j \mid I=8)$	53.24 (3.02)	38.97 (1.22)	14.27 (3.25)***	0.12 (0.02)	1.54 (1.14)	-1.42 (1.14)*	25.91 (1.98)	12.98 (0.49)	12.92 (2.04)***
Non-adopter	$E(Q_j \mid I=1)$	51.06 (0.99)	45.24 (0.61)	5.82 (1.17)***	0.05 (0.01)	1.12 (0.57)	-1.08 (0.57)**	19.99 (0.72)	17.05 (0.31)	2.95 (0.44)***
	$E(Q_j \mid I=1)$	52.31 (2.47)	45.24 (0.61)	7.07 (0.53)***	0.40 (0.04)	1.12 (0.57)	-1.01 (0.93)**	25.65 (1.22)	17.05 (0.31)	8.19 (1.22)***
	$E(Q_j \mid I=1)$	54.54 (0.44)	45.24 (0.61)	9.29 (0.75)***	2.11 (0.22)	1.12 (0.57)	0.99 (0.95)**	27.69 (0.40)	17.05 (0.31)	10.64 (0.51)***
	$E(Q_j \mid I=1)$	68.48 (2.21)	45.24 (0.61)	23.24 (2.29)***	0.002 (0.05)	1.12 (0.57)	-1.12 (0.57)**	23.05 (1.27)	17.05 (0.31)	5.99 (1.30)***
	$E(Q_j \mid I=1)$	58.79 (0.59)	45.24 (0.61)	13.55 (0.85)***	0.37 (0.05)	1.12 (0.57)	-0.77 (0.57)*	21.43 (0.26)	17.05 (0.31)	4.38 (0.40)***
	$E(Q_j \mid I=1)$	60.99 (3.75)	45.24 (0.61)	15.74 (3.79)***	0.36 (0.03)	1.12 (0.57)	-0.75 (0.57)*	28.26 (0.74)	17.05 (0.31)	11.20 (0.80)***

Note: 'j' represents combination of IAPs shown in table 1; figures in parenthesis are standard errors; *, ** and *** indicate statistical significance at 10%, 5% and 1% level

Table 6. Average value of N fertilizer uses (kg /acre) by participation in fertilizer subsidy program-unconditional average effects

AIPs combinations	With subsidy	Without subsidy	Difference
$I_0R_0V_0$	15.89 (0.54)	20.26 (1.57)	-4.36 (1.31)***
$I_1R_0V_0$	19.08 (0.81)	15.35 (1.33)	3.72 (1.83)**
$I_0R_1V_0$	27.57 (2.66)	17.27 (1.64)	10.29 (4.29)***
$I_0R_0V_1$	16.30 (0.53)	23.43 (1.49)	-7.12 (1.27)***
$I_1R_1V_0$	25.87 (2.85)	15.18 (3.39)	10.68 (6.01)**
$I_1R_0V_1$	20.18 (0.68)	14.82 (1.21)	5.36 (1.70)***
$I_0R_1V_1$	32.64 (2.41)	18.04 (1.56)	14.59 (4.81)***
$I_1R_1V_1$	28.02 (2.38)	13.73 (2.39)	14.28 (6.91)**

Note: figures in parentheses are standard errors; ** and *** indicate statistical significance at 5% and 1% level.

Table 7. Impact of IAPs on N fertilizer application with and without fertilizer subsidy (sample-adopters)

Outcome	With subsidy			Without subsidy		
	Adoption status		Adoption Effects	Adoption status		Adoption Effects
	Adopting (j= 2,. . .,8)	Non-Adopting (j=1)		Adopting (j= 2,. . .,8)	Non- Adopting (j=1)	
	A	B	C(A-B)	D	E	F(D-E)
$E(Q_j\|I = 2)$	23.88 (0.18)	14.21 (0.27)	9.67 (0.32)***	14.33 (1.24)	16.35 (1.07)	-2.02 (1.64)*
$E(Q_j\|I = 3)$	26.47 (1.86)	15.80 (0.56)	10.66 (1.95)***	14.43 (3.03)	20.65 (2.07)	-6.22 (3.66)**
$E(Q_j\|I = 4)$	32.08 (0-56)	19.82 (0.45)	12.26 (0.71)***	22.66 (1.09)	16.57 (1.84)	6.09 (2.14)***
$E(Q_j\|I = 5)$	22.19 (3.34)	14.02 (0.94)	8.17 (3.47)**	NR	NR	NR
$E(Q_j\|I = 6)$	24.81 (0.17)	14.73 (0.24)	10.08 (0.29)***	15.26 (2.12)	17.32 (1.39)	-2.06 (2.54)
$E(Q_j\|I = 7)$	25.23 (0.89)	15.31 (0.41)	9.92 (0.98)***	19.10 (1.75)	24.22 (2.28)	-5.11 (2.87)**
$E(Q_j\|I = 8)$	27.82 (1.93)	11.91 (0.58)	15.91 (2.02)**	NR	NR	NR

Note: 'j' represents package of IAPs shown in table 1; figures in parentheses are standard errors; *, ** and *** indicate statistical significance at 10%, 5% and 1% level. NR – the model does not converge because of few observations.

Table 8. Mean crop income difference between subsidy participants and non-participants

IAPs combinations	Net crop income ('000 MK/acre)		Difference
	With subsidy	Without subsidy	
$I_0R_0V_0$	46.37 (1.89)	44.56 (2.91)	1.82 (3.58)
$I_1R_0V_0$	50.39 (2.46)	38.24 (2.33)	12.15 (4.69)***
$I_0R_1V_0$	51.91 (4.31)	59.90 (7.43)	-7.99 (8.15)
$I_0R_0V_1$	47.11 (1.80)	51.42 (3.45)	-4.30 (3.73)
$I_1R_1V_0$	52.53 (5.22)	49.41 (8.21)	3.11 (11.07)
$I_1R_0V_1$	50.12 (2.05)	46.52 (3.02)	3.59 (4.98)
$I_0R_1V_1$	49.19 (3.96)	47.27 (5.44)	1.92 (8.09)
$I_1R_1V_1$	50.92 (4.57)	44.29 (9.51)	6.63 (12.13)

Note: figures in parentheses are standard errors; *** indicate statistical significance at 1% level.

Appendix

Table A1. Parameter estimates for the selection model of improved agronomic practices (reference category-$I_0R_0V_0$)

Variables	$I_1R_0V_0$		$I_0R_1V_0$		$I_0R_0V_1$		$I_1R_1V_0$		$I_1R_0V_1$		I_0R_1V
	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient
Household characterstics											
Gender	-0.322	0.289	-0.723**	0.327	-0.590**	0.236	-0.800*	0.478	-0.412	0.284	-0.215
Age	0.007	0.008	0.018*	0.009	-0.007	0.006	0.019	0.013	-0.003	0.007	0.014
Educhead	0.015	0.025	-0.008	0.028	0.022	0.020	0.014	0.043	0.031	0.024	0.016
Educspous	-0.016	0.032	0.045	0.039	0.037	0.025	0.077	0.053	0.069**	0.030	0.087**
Famlysize	0.058	0.049	0.026	0.054	0.031	0.035	0.186**	0.073	0.054	0.044	-0.061
Resource constraints											
Farmsize	0.009	0.026	-0.009	0.034	0.038**	0.018	-0.010	0.031	-0.053	0.062	0.023
Tlu	-0.005**	0.002	-0.033	0.034	-0.000	0.002	-0.004	0.003	-0.000	0.002	-0.001
Credtconst	0.017	0.174	0.219	0.246	-0.170	0.142	-0.047	0.294	-0.232	0.171	-0.129
Fertsubsidy	-5.368**	2.647	-5.034	3.561	0.451	2.139	-4.582	4.455	1.561	2.480	0.588
Market access											
Mktinputdist	0.006	0.006	0.007	0.007	-0.001	0.005	0.017***	0.006	0.009*	0.005	-0.010
Mktoutdist	0.000	0.003	-0.003	0.004	-0.003	0.002	-0.005	0.004	0.001	0.003	-0.005
Timeseed	0.271	0.190	0.119	0.242	0.422***	0.149	0.430	0.313	0.285*	0.173	-0.036
Priceseed	0.272	0.184	-0.022	0.227	0.239	0.148	-0.028	0.333	0.419**	0.179	0.130
Qualtyseed	-0.365	0.236	0.547*	0.282	-0.093	0.188	0.094	0.394	-0.030	0.222	0.579**
Social capital network and extension service access											
Trader	0.019*	0.010	0.022**	0.011	0.000	0.008	0.026**	0.012	0.016*	0.009	0.021*
Kinship	0.028*	0.015	0.011	0.018	-0.007	0.013	0.073***	0.023	0.009	0.014	-0.010
Group	0.083	0.103	-0.104	0.129	0.085	0.088	0.094	0.176	-0.072	0.103	-0.076
Distext	-0.001*	0.001	-0.002	0.002	-0.000	0.001	-0.001	0.002	0.001	0.001	0.000
Extenskill	-0.012	0.197	0.129	0.241	-0.075	0.157	0.214	0.302	-0.292	0.193	0.213
Shocks											
Rainfalindex	0.583**	0.297	0.332	0.391	-0.129	0.245	-0.280	0.463	0.016	0.280	0.285
Pestsdisease	0.340*	0.192	0.236	0.244	0.046	0.167	-0.119	0.346	0.326*	0.191	0.188
Plot characterstics											
Plotdist	0.007	0.006	0.014*	0.009	0.004	0.007	0.004	0.011	0.005	0.006	-0.008
Tenure	1.059	0.661	-0.623	1.250	0.455	0.554	0.979	1.407	0.958	0.585	-1.154*
Womnmangr	2.124**	0.871	-0.552	1.625	0.721	1.103	-2.108	1.628	2.396**	1.059	-1.992
Menmangr	2.660**	1.159	-0.727	1.551	1.755	1.173	-0.654	2.312	3.067***	1.141	-2.287
Goodsoilplt	-0.208	0.649	-1.771**	0.766	-0.115	0.566	-2.178***	0.806	-0.188	0.618	-0.725
Medmsolplt	-0.577	0.674	-1.717**	0.833	-0.542	0.578	-1.485	0.941	-0.684	0.623	-0.712
Flatslop	-1.086**	0.477	-0.408	0.841	-0.200	0.433	-0.031	0.791	-0.647	0.450	-0.560
Medumslop	-0.598	0.526	0.426	0.957	-0.261	0.514	-0.412	0.934	-0.427	0.499	-0.345
Shalwdepth	0.803	0.540	0.857	0.813	-0.005	0.470	1.739*	0.892	1.047**	0.498	-0.568
Medmdepth	1.163***	0.449	1.583**	0.759	0.330	0.393	1.666	1.019	1.333***	0.394	0.911
Manureuse	0.632*	0.358	0.538	0.613	0.495	0.322	0.087	0.697	0.407	0.353	0.273
Constant	1.927	1.589	1.927	2.056	0.706	1.292	-2.140	2.830	-2.468	1.536	-1.711
Joint-significance of location variables: χ^2 (15)	203.35***		1831.89***		18.91		4147.41***		172.86***		1713.82
Joint-significance of mean of plot varying covariates : χ^2 (11)	21.51**		21.53**		8.03		21.51**		23.51***		14.06

Variables	$I_1R_0V_0$		$I_0R_1V_0$		$I_0R_0V_1$		$I_1R_1V_0$		$I_1R_0V_1$		I_0R_1V
	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient
Number of observations = 2922; Wald χ^2 (413)= 44225.72; p > χ^2 = 0.000											

Note: SE is robust standard errors; *, ** and *** indicate statistical significance at 10%, 5% and 1% level

Table A2. Parameter estimates for the crop net income equation , Dependent variable: crop net income (MK/acre)

Variables	$I_0R_0V_0$		$I_1R_0V_0$		$I_0R_1V_0$		$I_0R_0V_1$		$I_1I_1V_0$		$I_1R_0V_1$		
	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE	Co
Household characterstics													
Gender	9.783	19.23	-17.418	20.699	17.135	41.39	19.556***	6.160	23.699	122.99	0.952	8.072	-1
Age	0.091	0.251	0.286	0.188	0.060	0.578	0.362***	0.119	1.227	0.929	-0.265	0.182	0
Educhead	-0.308	1.528	2.013***	0.706	-0.609	1.764	-0.306	0.358	-2.257	10.115	-0.142	1.141	-
Educspous	-1.218	1.175	0.667	1.324	3.998	3.961	0.594	0.975	-0.011	11.690	-0.569	0.792	
Famlysize	-0.015	1.062	2.205	1.629	-0.366	3.829	-0.545	0.472	-4.834	17.756	2.571***	0.566	3
Resource constraints													
Farmsize	-2.500***	0.452	-1.603	1.304	1.095	3.105	-2.610***	0.702	0.383	20.246	0.039	0.680	-3.
Tlu	0.039	0.157	-0.185	0.531	1.054	5.208	-0.073*	0.041	-0.620	9.458	0.008	0.166	-
Credtconst	2.877	4.088	-4.016	4.132	-3.623	11.53	4.928	3.285	22.659	33.866	0.654	10.43	1
Fertsubsidy	22.943	67.37	32.740	69.642	197.69***	74.90	-45.216***	16.371	-196.551	431.31	69.659	73.15	-1
Market access and Social capital network													
Mktoutdist	0.082	0.075	0.050	0.047	-0.104	0.469	0.043	0.080	0.179	0.501	-0.078	0.110	0
Timeseed	-18.70**	7.657	6.510*	3.781	0.724	38.36	-7.184***	2.176	-50.288	62.972	-6.071	5.881	1
Priceseed	-6.271*	3.396	8.838*	5.336	-0.250	18.63	-8.978***	1.052	-5.105	43.653	-7.463	5.953	5
Qualtyseed	-1.973	6.376	-12.864	11.682	-17.574	29.54	6.793*	3.592	44.821	103.67	-4.110	10.37	27
Trader	0.299	0.205	-0.188	0.370	-0.558	1.429	0.654***	0.206	0.701	3.287	-0.369**	0.150	-
Shocks													
Rainfalindex	4.816	11.936	22.79***	8.576	11.746	41.97	10.643	9.577	35.898	136.28	-0.249	8.788	4
Pestsdisease	4.710	6.634	-6.866	6.256	-17.086	19.62	-0.677	6.140	-37.429	91.021	-14.69***	2.752	3
Plot characterstics													
Plotdist	-0.183	0.350	0.241	0.420	-1.006	0.809	-0.266	0.190	-0.795	2.227	-0.118	0.198	-
Tenure	1.583	16.084	-6.233	18.024	-82.927	119.9	-16.895	23.855	-178.964	350.39	27.974	37.73	-1
Womnmangr	120.066	136.65	56.469*	30.785	-12.297	203.6	-0.948	22.493	-449.9***	49.729	-29.900	66.96	5
Menmangr	88.363	125.41	95.505	100.71	41.784	186.5	-48.806*	28.133	-442.273	351.75	-44.029	58.23	2
Goodsoilplt	1.552	18.025	4.411	15.432	-12.021	48.96	44.040	28.992	-133.598	257.29	-14.338	9.327	2
Medmsolplt	9.899	11.898	-10.882	25.871	6.145	77.40	32.382	22.692	25.363	219.89	-18.675	31.79	65
Flatslop	13.025	12.799	12.878	15.853	-28.644	79.10	-15.684	16.354	53.162	195.83	12.604	15.35	2
Medumslop	24.263	14.924	9.795	18.705	-49.650	54.28	-5.555	16.145	18.632	148.67	-0.292	16.95	6
Shalwdepth	-2.799	18.952	-6.114	19.327	31.627	64.37	6.488	23.580	-25.123	202.34	11.350	25.33	-3
Medmdepth	-5.599	19.812	-0.264	26.763	-40.080	89.83	18.978	14.140	-39.094	202.25	13.381	22.20	1
Manureuse	0.780	11.501	27.133	32.213	11.022	73.32	-6.158	10.279	-3.693	130.30	1.398	7.501	-9
Constant	-39.208	38.110	32.206	21.624	-56.076	125.1	116.94***	27.123	57.233	426.98	54.526	71.90	9
Anciliary													
λ1			-0.638	0.653	-0.866	0.868	0.677	0.713	0.412	0.806	0.541	0.488	0
λ2	0.280	0.700			-0.406	1.005	0.085	0.524	-0.200	0.288	-0.216	0.411	-
λ3	0.820	0.849	0.395	0.711			0.915***	0.252	0.388	0.541	-1.343**	0.588	0
λ4	-0.982	0.649	1.016**	0.494	0.019	0.678			-0.932	0.753	0.739*	0.447	-
λ5	-0.000	0.487	-0.233	0.384	0.503	0.426	-1.190*	0.698			0.736	0.484	-1.
λ6	-0.033	0.436	0.478*	0.266	-0.654**	0.300	-0.466	0.381	-0.594	0.606			0.8
λ7	-0.606	0.444	-0.638	0.932	0.747***	0.275	0.322	0.316	1.019	0.716	-0.552	0.683	
λ8	0.040	0.600	-0.344	0.548	0.799*	0.440	-0.018	0.629	-0.097	0.435	0.153	0.743	0
Joint-significance of location variables	F(15, 507) =1.12		F(15, 414) =1.63*		F(12, 107) = 1.17		F(15, 659) = 0.93		F(13, 32) = 1.02		F(15, 487) = 1.43		F(
Joint-significance of mean of plot	F(11, 507) =1.23		F(11, 414) = 0.76		F(11, 107) = 0.59		F(11, 659) = 1.57*		F(11, 32) = 1.27		F(11, 487) = 1.23		F(1

Variables	$I_0R_0V_0$		$I_1R_0V_0$		$I_0R_1V_0$		$I_0R_0V_1$		$I_1I_1V_0$		$I_1R_0V_1$		
	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE	Co
varying covariates													
Test of instruments													
First stage			χ^2 (5)=5.92		χ^2 (5)=3.80		χ^2 (5)=1.72		χ^2 (5)=14.93***		χ^2 (5)=8.40		
Second stage			F(5, 400) =	0.35	F(5, 156) =	1.48	F(5, 619) =	0.79	F(5, 87) =	0.81	F(5, 455) =	1.63	F(

Note: SE is bootstrapped standard errors; *, ** and *** indicate statistical significance at 10%, 5% and 1% level. Instruments used: Mktinputdist, Kinship, Group, Distext and Extenskill.

Table A3. Parameter estimates for the pesticide application equation, Dependent variable: quantity of pesticides use (lit./acre)

Variables	$I_0R_0V_0$		$I_1R_0V_0$		$I_0R_1V_0$		$I_0R_0V_1$		$I_1R_1V_0$		$I_1R_0V_1$		
	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE	C
Household characterstics													
Gender	0.000	0.000	-0.046	0.079	0.670	1.788	0.000	1.627	0.102	1.448	0.427	0.431	
Age	0.031	0.179	-0.004	0.003	-0.015	0.022	0.160	0.137	-0.009	0.039	0.005	0.009	
Educhead	-0.904*	0.464	0.008	0.005	-0.027	0.102	0.288	0.261	-0.002	0.046	-0.037	0.037	
Educspous	-0.400	0.377	0.012*	0.007	0.020	0.126	0.456	0.388	-0.025	0.071	0.008	0.051	
Famlysize	1.348**	0.659	-0.001	0.010	-0.149	0.148	-0.026	0.584	-0.082	0.213	0.008	0.045	
Resource constraints													
Farmsize	-0.348**	0.176	-0.019*	0.011	0.039	0.154	-0.185	0.743	0.056	0.325	-0.070	0.082	
Tlu	2.315***	0.605	0.002	0.003	0.059	0.089	-0.118	1.766	0.031	0.191	-0.003	0.004	
Credtconst	-1.431	2.256	-0.109**	0.044	-0.400	0.878	-0.367	0.795	-0.081	0.554	0.121	0.315	
Fertsubsidy	-6.394	0.000	1.301	1.078	5.326	6.639	-1.623	2.560	0.590	1.845	-1.829	4.043	
Market access													
Mktinputdist	0.123	0.316	0.005***	0.001	-0.022	0.020	-0.035	0.084	-0.005	0.021	0.005	0.005	
Mktoutdist	-0.040	0.031	0.002	0.001	-0.000	0.002	0.019	0.031	-0.000	0.010	0.005	0.008	
Social capital network and extension													
Trader	-0.186*	0.104	-0.002	0.002	-0.046*	0.025	-0.109	0.225	-0.025	0.029	0.016	0.014	
Kinship	0.949***	0.366	-0.001	0.006	-0.047	0.055	0.242	0.194	-0.038	0.063	0.028	0.027	
Group	-6.023***	0.119	0.021	0.054	0.766	0.739	0.391	0.552	-0.036	0.262	0.000	0.108	
Distext	-0.151***	0.044	0.001	0.002	0.010	0.010	-0.023	0.023	-0.001	0.038	0.000	0.002	
Extenskill	-1.437**	0.655	-0.083	0.097	0.056	0.414	0.000	0.000	-0.020	0.733	0.011	0.242	
Shocks													
Rainfalindex	0.000	0.000	-0.139	0.125	-0.686	0.421	-0.966	1.142	-0.031	0.603	0.585***	0.195	
Pestsdisease	0.737	0.577	0.074***	0.010	-0.216	0.571	-4.379***	0.554	0.058	0.531	0.506	0.455	
Plot characterstics													
Plotdist	-0.320***	0.044	-0.002	0.002	-0.044***	0.002	0.134	0.125	-0.002	0.011	0.012	0.013	
Tenure	0.000	0.000	-0.289	0.435	-0.724	2.549	1.847	0.000	-1.039	0.881	-0.503	0.822	
Womnmangr	0.000	0.000	-0.931**	0.470	-1.837	3.397	0.874	0.000	-6.378***	0.213	-2.776	4.861	
Menmangr	0.000	0.000	-0.936	1.134	-1.521	4.588	0.775	2.133	-6.049	7.267	4.682	8.042	
Goodsoilplt	16.553***	3.210	-0.436	0.362	2.968	1.996	0.000	1.201	0.505	3.947	0.263	0.430	
Medmsolplt	0.000	0.000	-0.481	0.329	2.817	2.112	-3.521***	0.667	0.567	1.705	-0.336	0.976	
Flatslop	0.000	0.000	0.112	0.146	0.699***	0.151	4.900***	1.319	-0.159	0.410	0.740	1.398	
Medumslop	0.000	0.000	-0.044	0.092	-1.666	1.337	-0.318	0.828	-0.008	2.694	0.753	1.453	
Shalwdepth	0.000	0.000	0.083	0.177	-3.287	2.320	0.000	0.000	-0.978	2.464	-0.208	0.673	
Medmdepth	3.237***	1.078	-0.020	0.199	-3.001*	1.606	1.417*	0.854	-0.728	4.021	1.228	2.149	
Manureuse	0.000	0.000	-0.003	0.115	-1.538*	0.878	0.431*	0.232	-0.020	0.979	0.432	0.533	
Constant	-12.998	15.67	-0.417	0.393	5.048	5.851	-7.597	8.552	3.428	2.919	-2.385	5.162	
Anciliary													
λ1			0.254*	0.134	0.701	0.618	0.000	0.000	0.493	0.507	0.210	0.479	
λ2	0.644	0.730			-0.769	0.539	1.610**	0.777	-0.507	0.581	0.610***	0.195	
λ3	0.000	0.952	-0.101	1.015			0.000	0.000	0.449	0.873	-0.045	0.440	
λ4	0.000	0.000	-0.372	0.672	0.330	0.648			0.681***	0.251	-1.219***	0.313	
λ5	0.000	0.000	0.087	0.453	0.235	1.214	0.000	0.000			-0.012	0.485	
λ6	-1.509**	0.761	1.080***	0.136	0.063	0.518	0.000	0.870	-1.073*	0.640			
λ7	0.000	0.000	0.238	0.833	0.837***	0.323	0.000	0.000	0.025	0.723	0.445	0.703	
λ8	0.000	0.000	-1.102	0.954	-1.003	0.819	0.000	0.000	0.137	0.797	-0.125	0.650	
Joint-significance of			F(15, 408) =	1.13	F(12, 105) =	0.91			F(13, 29) =	1.27	F(15, 482) =	0.92	F

Variables	$I_0R_0V_0$		$I_1R_0V_0$		$I_0R_1V_0$		$I_0R_0V_1$		$I_1R_1V_0$		$I_1R_0V_1$		
	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE	C
location variables													
Joint-significance of mean of plot varying covariates			F(11,408) = 2.61***		F(11, 105) = 0.53				F(11, 29) = 4.89***		F(11, 482) =8.19***		F
Test of instruments First stage:			χ^2 (3)=6.18*		χ^2 (3)=4.60		χ^2 (3)= 14.88***		χ^2 (3)=2.36		χ^2 (3)= 12.45***		
Second stage:			F(3, 398) = 1.26		F(3, 156) = 0.39				F(3, 86) = 0.85		F(3, 453) = 1.09		F

SE is bootstrapped standard errors; *, ** and *** indicate statistical significance at 10%, 5% and 1% level; None is the reference category; Instrument used: Timeseed, Priceseed, and Qualtyseed

Table A4. Parameter estimates for the fertilizer (nitrogen) application equation, Dependent variable: quantity of nitrogen fertilizer (kg/acre)

Variables	$I_0R_0V_0$		$I_1R_0V_0$		$I_0R_1V_0$		$I_0R_0V_1$		$I_1R_1V_0$		$I_1R_0V_1$		
	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE	C
Household characterstics													
Gender	-4.799***	1.261	-4.274	5.005	-28.926	20.441	2.719*	1.388	12.787	65.072	-3.058	4.860	
Age	-0.076	0.146	-0.055	0.141	-0.124	0.432	0.142*	0.085	-1.393*	0.803	-0.030	0.101	
Educhead	0.001	0.236	0.027	0.424	-1.693	2.105	0.178	0.297	1.440	5.685	0.241	0.259	
Educspous	-0.033	0.401	1.020*	0.598	-0.240	0.950	-0.456	0.280	-5.694	6.457	-0.142	0.571	
Famlysize	0.459**	0.228	0.994	1.005	4.026**	1.861	0.419	0.397	-7.123	8.776	0.530	0.488	
Resource constraints													
Farmsize	1.674***	0.287	-0.072	0.761	1.496	4.067	0.088	0.406	11.062	7.349	0.589	0.953	
Tlu	0.114***	0.031	-0.092	0.725	2.588	3.110	-0.025	1.157	-0.469	4.271	-0.019	0.040	
Credtconst	-2.885	1.962	-2.849***	1.019	1.441	9.321	0.195	1.658	4.903	16.777	-1.022	1.736	
Fertsubsidy	7.762	43.41	71.250	65.377	-151.254	145.39	-40.227***	13.137	153.16***	36.707	10.579	29.811	
Market access													
Mktinputdist	-0.062	0.052	0.098	0.063	-0.228	0.557	0.037	0.059	-0.750	0.499	-0.033	0.090	
Mktoutdist	-0.032	0.026	0.068***	0.016	-0.192	0.296	0.015	0.017	-0.067	0.297	-0.042***	0.010	
Social capital network and extension													
Trader	-0.116	0.159	0.165	0.102	-0.186	0.335	-0.073	0.133	-3.380	2.608	0.004	0.132	
Kinship	-0.132	0.297	-0.194	0.409	-0.143	1.659	0.171	0.216	-4.236***	1.314	-0.200	0.204	
Group	-0.613	0.857	-0.531	2.378	4.627	6.767	-0.618	0.747	-4.818	14.120	2.119	2.637	
Distext	-0.003	0.012	0.029	0.063	-0.160	0.139	-0.004	0.031	-0.021	0.558	-0.016***	0.006	
Extenskill	1.421	1.486	-3.208	4.164	6.308	9.608	-0.880	1.708	-28.635	31.036	0.911	0.798	
Shocks													
Rainfalindex	-2.890	4.515	-2.984	6.241	0.071	11.843	6.583***	2.213	5.154	40.212	-5.343*	3.017	2
Pestsdisease	3.112**	1.318	-0.007	3.710	-11.426	9.131	4.471	2.951	-6.716	71.103	-2.516	2.374	
Plot characterstics													
Plotdist	0.070	0.103	0.015	0.068	0.321	0.809	0.073**	0.034	-0.284	0.505	0.141***	0.054	
Tenure	2.921	11.90	7.665	11.284	1.177	61.134	7.312	12.174	-108.172	103.39	5.986	24.625	
Womnmangr	-15.788	18.86	-13.321	21.019	21.451	57.136	24.993**	10.320	108.346*	55.680	22.060	43.687	
Menmangr	-12.613	27.29	11.367	35.180	27.470	82.931	18.004	27.889	68.701	155.77	17.501	42.207	
Goodsoilplt	-3.896	7.221	-16.293**	6.880	10.030	50.333	-0.711	3.643	61.704	63.813	12.401***	3.879	
Medmsolplt	3.019	4.709	-17.247***	5.933	1.010	64.657	2.870	3.072	30.565	62.929	9.082***	1.899	
Flatslop	8.637	5.795	-0.488	5.204	-4.385	28.100	0.189	7.981	15.292	47.378	7.829	5.338	
Medumslop	4.904	6.610	-4.694**	2.193	-25.783	42.487	5.216	3.775	7.294	51.374	7.740	4.944	
Shalwdepth	-10.377	6.869	8.222	12.898	21.848	28.449	14.731	10.970	-39.853	148.52	-0.299	10.246	
Medmdepth	-12.285*	7.077	5.547	10.733	16.264	41.947	10.079	8.023	-63.815	157.20	5.220	8.505	
Manureuse	-1.054	3.400	4.056	4.186	-6.829	28.317	-4.805	4.754	-12.045	77.961	-1.618	4.121	
Constant	26.014	28.67	-32.725	20.565	132.264	139.09	41.624***	10.233	408.49***	116.30	43.302	42.041	
Anciliary													
λ1			-0.328	0.517	-0.019	0.440	0.290	0.553	0.661	0.572	-0.524	0.659	
λ2	-0.304	0.678			0.478	0.631	0.506	0.322	-0.476	0.866	-0.076	0.364	
λ3	0.005	0.582	-0.147	0.720			1.007	0.791	0.688	0.505	-0.393	0.384	
λ4	1.218*	0.672	-0.368	0.502	0.434	0.322			0.802*	0.421	1.149**	0.556	
λ5	-0.052	0.268	0.897	0.847	-0.227	0.859	-0.282	0.541			0.525	0.400	
λ6	-0.549	0.500	1.057***	0.347	-1.023***	0.270	-0.094	0.401	-0.408	0.787			
λ7	-0.059	0.339	-0.384	0.556	-0.749	0.749	-1.186***	0.400	-0.843***	0.070	-0.590	0.610	
λ8	-0.314	0.505	-0.620	0.450	1.029***	0.189	-0.010	0.519	-0.260	0.439	0.116	0.387	

Variables	$I_0R_0V_0$		$I_1R_0V_0$		$I_0R_1V_0$		$I_0R_0V_1$		$I_1R_1V_0$		$I_1R_0V_1$		
	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE	C
Joint-significance of location variables:	F(15, 424)=2.63***		F(15, 362) =	0.75	F(11, 84) =	0.81	F(15, 578) =	1.95**	F(13, 19) =	1.17	F(15, 458) =	0.60	F
Joint-significance of mean of plot varying covariates	F(11,424) =	1.64*	F(11, 362) =	0.80	F(11, 84) =	0.74	F(11, 578) =	2.15**	F(11, 19) =	1.60	F(11, 458) =	1.40	F
Test of instruments													
First stage:			χ^2(3)=6.18*		χ^2(3)= 4.60		χ^2(3)= 14.88***		χ^2(3)=2.36		χ^2(3)= 12.45***		
Second stage			F(3, 358) =	1.30	F(3, 137) =	0.82	F(3, 563) =	4.81***	F(3, 77) =	0.14	F(3, 436) =	0.34	F

Note: SE is bootstrapped standard errors; *, ** and *** indicate statistical significance at 10%, 5% and 1% level; None is the reference category; Instrument used: Timeseed, Priceseed, and Qualtyseed.