Citation for the published paper:

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Ecological Economics, 93 s. 85-93

http://dx.doi.org/10.1016/j.ecolecon.2013.05.002

Cropping system diversification, conservation tillage and modern seed adoption in Ethiopia: Impacts on household income, agrochemical use and demand for labor

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Abstract

The type and combination of sustainable agricultural practices (SAPs) adopted has a significant effect on agricultural productivity and food security. This study develops a multinomial endogenous switching regression model of farmers' choice of combination of SAPs and impacts on maize income and agrochemicals and family labor use in rural Ethiopia. Four primary results were found. First, adoption of SAPs increases maize income and the highest payoff is achieved when SAPs are adopted in combination rather than in isolation. Second, nitrogen fertilizer use is lower in the package that contains systems diversification and conservation tillage. Third, conservation tillage increased pesticide application and labor demand, perhaps to compensate for reduced tillage. However, when it is used jointly with systems diversification, it does not have a significant impact on pesticide and labor use. Fourth, in most cases adoption of a package of SAPs increases women workload, suggesting that agricultural intensification technology interventions may not be gender neutral. This implies that policy makers and other stakeholders promoting a combination of technologies can enhance household food security through increasing income and reducing production costs, but need to be aware of the potential gender related outcomes.

Keywords

Ethiopia; Agrochemical use; Labour demand; Maize income; Multinomial switching regression; Sustainable agricultural practices

1. Introduction

The major challenge facing sub-Saharan African (SSA) governments today is how to achieve food security and reduce poverty, while simultaneously mitigating degradation of essential ecosystem services. Most attention in the literature has been given to the low and stagnant returns from African agriculture (World Bank, 2007; Bluffstone and Köhlin, 2011; Jhamtani, 2011; Pretty et al., 2011). However, many ecosystem services, including nutrient cycling, nitrogen fixation, soil regeneration, and biological control of pests and weeds, are under threat in key African food production systems that are vital for sustainable food security. The causes of environmental degradation in SSA include declining fallow periods, inadequate investment in sustainable intensification, and a strong trajectory away from diversification in favor of mono-cropping in otherwise traditionally complex farming systems (Pretty, 1999; Lee, 2005; Woodfine, 2009; Snapp et al., 2010; Jhamtani, 2011). These trends have contributed to low agricultural productivity and food insecurity in SSA and will continue to do so at an accelerating rate under anticipated climate change.

Unfortunately, there is a risk of a trade-off between attempts to increase the productivity in African agriculture through “modernization packages,” which combine improved seed varieties with agrochemicals, and the resulting stress that these inputs place on ecosystem services. The loss of ecosystem services can in turn require greater use of agrochemicals (such as chemical fertilizers and pesticides) and can increase the demand for on-farm labor. For example, increased use of external inputs is needed to regulate pests and diseases under increasingly simplified mono-cropping systems. Weed and pest populations previously controlled by ecosystem services now require the use of pesticides (Fuglie, 1999; Knowler and Bradshaw, 2007) and/or more labor is needed to control them. In addition, if agrochemicals are not properly used, they can cause significant harm to the environment and human health.

In this context, Sustainable Agricultural Practices (SAPs)[1] are strategies that can increase productivity in a sustainable way by addressing the degradation of ecosystem services and

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[1] We define SAPs for agricultural intensification and productivity growth in farming systems more broadly to include conservation tillage (zero or reduced tillage), cropping bio-diversification (legume intercropping and crop rotations), improved crop varieties, use of animal manure, complementary use of organic fertilizers, and investment in soil and water conservation (FAO, 1989; Lee, 2005; Kassie et al., 2010; Wollni et al., 2010; Pretty et al., 2011).

increasing the ability of smallholder farmers to adapt to climate variability and change (Antle and Diagana, 2003; Lee, 2005; Woodfine, 2009; Pretty et al., 2011).

This paper will analyze the application of various combinations of three SAPs. The first one is cropping system diversification (maize–legume rotation). This system provides many ecosystem services, including N fixation and C sequestration; breaking the life cycle of pests; improving weed suppression; and smoothing out the impacts of price fluctuations (Liebman and Dyck, 1993; Altieri, 1999; Tilman et al., 2002; Woodfine, 2009; Di Falco et al., 2010; Snapp et al., 2010; Jhamtani, 2011;). This can save farmers the cost of fertilizer and pesticides. Minimizing the use of these inputs also contributes to the mitigation of climate change. System diversification enables farmers to grow products that can be harvested at different times and places and that have different weather or environmental stress-response characteristics. These varied outputs and degrees of resilience are a hedge against the risk of drought, extreme or unseasonal temperatures, rainfall variations and price fluctuations, all of which affect the productivity and income of smallholder systems.

The second SAP is adoption of conservation tillage. This can lead to substantial ecosystem services benefits by reducing soil erosion and nutrient depletion and conserving soil moisture (Fuglie, 1999; Tilman et al., 2002; Woodfine, 2009).

The third SAP considered is the introduction of modern seeds (Lee, 2005). In our case, the improved maize varieties used are primarily intended to increase yields, mostly augmented with fertilizer and pesticides, thus addressing food security and income needs (Bellon and Taylor, 1993; Fernandez, 1996). Adoption of improved seeds is likely to be an important strategy in adaptation to future climate change.

In this paper, we analyse adoption of a combination of these SAPs and their impacts on income and agrochemical use. Specifically, the paper focuses on two objectives. First, we analyse the factors motivating the adoption of a combination of SAPs (i.e., cropping system diversification, conservation tillage and modern maize seed) in the maize–legume farming system of Ethiopia. Second, we examine the implications of adopting various combinations of these practices on selected outcome variables; more specifically, maize income[2], use of agrochemicals such as N fertilizer and pesticides (insecticides and herbicides), and demand for agricultural

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[2] This is the net maize income after fertilizer, seed, labour and pesticide costs have been accounted for.

female and male labor. We control for selection bias using a multinomial endogenous switching treatment effects approach.

Despite the multiple benefits of SAPs and considerable efforts by national and international organizations to encourage farmers to invest in them, there is still a lack of evidence on farmers' incentives and conditioning factors that hinder or accelerate adoption of inter-related SAPs. An improved understanding of farmers' adoption behavior and the potential economic and agrochemical use implications associated with adoption of these practices is therefore important for sustainable intensification in the region.

This paper adds to existing literature on adoption analysis and impacts of technology in the following ways. First, we investigate (for the first time, to our knowledge) whether adoption of SAPs in combination will provide more economic benefits and better regulate agrochemical use than adopting them individually. This knowledge is relevant to the debate on whether farmers should adopt technologies piecemeal or in a package. It is also valuable for designing effective extension policies by identifying a combination of technologies that deliver the highest payoff. Most previous adoption studies (e.g., Gebremedhin and Scott, 2003; Kassie et al., 2010; 2011) have focused on analysis of a single SAP using single equation models (e.g., probit or logit). However, farmers are faced with technology alternatives that may be adopted simultaneously as complements, substitutes or supplements to deal with their overlapping constraints, such as weeds, pest and disease infestations, and low soil fertility and crop productivity (Dorfman, 1996; Khanna, 2001, Moyo and Veeman, 2004). Earlier studies also ignore the possibility of a path or state of dependence: the choice of technologies adopted more recently by farmers may be partly dependent on earlier technology choices (Wu and Babock, 1998; Khanna, 2001). Adoption and impact analysis of technologies that ignoring these inter-relationships may underestimate or overestimate the influence of various factors on the adoption decision and on the impacts of adoption (Wu and Babcock, 1998). Modeling technology adoption and impact analysis in a multiple technology choice framework is therefore important to capture useful economic information contained in interdependent and simultaneous adoption decisions (Dorfman, 1996).

Our second contribution is the use of comprehensive household and plot-level survey data covering major maize growing regions in Ethiopia. This has allowed us to include several policy relevant variables (e.g., governance indicators, kinship, rainfall, and pest and disease shocks, and farmers' expectations of social safety nets or social insurance during crop failure) that determine

SAP adoption and outcome variables. These variables for which we have data were not considered in previous studies. Third, we contribute to the scant empirical evidence on the impacts of SAP adoption on agrochemical and labor use.

The rest of the paper is organized as follows. Section 2 provides a brief description of the data. Section 3 presents a conceptual and econometric framework for a multinomial adoption selection model and estimation of average treatment effects. This is followed by a presentation of the empirical specifications of our estimation model. In section 5, we discuss our estimation results. The final section concludes and draws key findings and policy implications.

2. The Data and Definitions of Variables

The dataset used for this study is based on a farm household survey conducted in Ethiopia during October–December 2010 by the Ethiopian Institute of Agricultural Research (EIAR) in collaboration with the International Maize and Wheat Improvement Center (CIMMYT). The sample consists of 900 farm households and about 1,644 farming plots. A multistage sampling procedure was employed to select peasant associations (PAs)[3] from each district and households from each of the PAs. First, based on their maize–legume production potential, nine districts from the three regional states of Ethiopia (Amhara, Oromia and SNNRP) were selected. Second, based on proportionate random sampling, 3 to 6 PAs in each district, and 16 to 24 farm households in each PA, were selected.

The SAPs considered in this study include system diversification (maize–legume rotation), conservation tillage, and improved maize seeds, providing eight possible combinations of SAPs (2^3). Table 1 presents the proportions of maize area cultivated under SAPs packages. Of the 1,644 maize plots, about 25% did not receive any of the SAPs ($R_0V_0T_0$), while all three practices were simultaneously adopted on 5.4% of the plots ($R_1V_1T_1$).

[Table 1 here]

Table 2 shows the interdependence of SAPs packages. Cropping system diversification is practiced on about 23% of the plots. Maize is often rotated with legumes such as haricot bean and soybeans. Sampled farmers used conservation tillage on about 36.3% of plots. Conservation tillage in our study refers to either reduced tillage (only one pass) or zero tillage combined with

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[3] A PA is the lowest administrative structure in Ethiopia.

letting the residue remain on the plot. Improved maize variety is adopted on 53% of the maize plots. The sample unconditional and conditional probabilities presented in Table 2 highlight the existence of interdependence across the three SAPs. For instance, the conditional probability of a household adopting conservation tillage is increased from 36% to 50% when farmers adopt system diversification. Similarly, the conditional probability of a household adopting modern maize seeds increases from 53% to 58% when farmers adopt system diversification. These results indicate complementarity among the adoption of system diversification, conservation tillage, and modern maize varieties.

[Table 2 here]

Descriptive statistics of explanatory variables for the eight sub-groups of observation are presented in Table 3.

[Table 3 here]

3. Conceptual and Econometric framework

In a multiple adoption setting, farmers' simultaneous adoption of cropping system diversification, conservation tillage, and an improved maize variety leads to eight possible SAP combinations options that a farmer could choose. The actual choice is expected to be based on the farmer's expected profit from adoption given his/her constraints. We model farmers' choice of SAP packages (i.e., alternative combinations of system diversification, conservation tillage, and modern maize seed) and outcome variables (maize income per hectare, agrochemical use, and female and male labor demand) in a multinomial endogenous switching regression (ESR) framework.

The effects of adoption are often determined by comparing relevant variables across plots adopting different SAPs. This approach may be appropriate for controlled experiments but not for empirical analysis using observational data, because of self-selection. Farmers endogenously self-select themselves into adoption/non-adoption decisions, so decisions are likely to be influenced by unobservable characteristics (for example, expectation of yield gain from adoption, managerial skills, and/or motivation) that may be correlated with the outcomes of interest. This requires a selection correction estimation method. We apply a multinomial ESR treatment effects approach following Dubin and McFadden (1984) (hereafter referred to as the DM model) and

Bourguignon et al. (2007) to correct selection bias. This framework has the advantage of evaluating alternative combinations of practices as well as individual practices. It also captures both self-selection bias and the interactions between choices of alternative practices (Mansur et al., 2008; Wu and Babcock, 1998).

In the first stage, farmers' choice of combinations/packages[4] of SAPs is modeled using a multinomial logit selection model,[5] while recognizing the inter-relationships among the choices. In the second stage of the estimation, the impacts of each combination of SAPs on outcome variables are evaluated using ordinary least squares (OLS) with a selectivity correction term from the first stage.

3.1. Multinomial adoption selection model

We assume that farmers aim to maximize their profit, U_i, by comparing the profit provided by m alternative packages. The requirement for farmer i to choose any package, j, over any alternative package, m, is that $U_{ij} > U_{im}\ m \neq j$, or equivalently $\Delta U_{im} = U_{ij} - U_{im} > 0\ m \neq j$. The expected profit, U_{ij}^*, that the farmer derives from the adoption of package j is a latent variable determined by observed household, plot and location characteristics (X_i) and unobserved characteristics (ε_{ij}):

$$U_{ij}^* = X_i \beta_j + \varepsilon_{ij}, \tag{1}$$

where X_i is observed exogenous variables (household, plot and location characteristics) and ε_{ij} is unobserved characteristics. Let (I) be an index that denotes the farmer's choice of package, such that:

$$I = \begin{cases} 1 \text{ iff } U_{i1}^* > \max\limits_{m \neq j}(U_{im}^*) \text{ or } \eta_{i1} < 0 \\ \vdots \quad\quad \vdots \quad\quad\quad\quad \vdots \\ J \text{ iff } U_{iJ}^* > \max\limits_{m \neq J}(U_{im}^*) \text{ or } \eta_{iJ} < 0 \end{cases} \quad \text{for all } m \neq j \tag{2}$$

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[4] We use combination and package interchangeably in this paper.

[5] Using Monte-Carlo experiments, Bourguignon et al. (2007) show that selection bias correction based on the multinomial logit model can provide good correction for the outcome equation, even when the IIA (Independent and Irrelevant Alternative) hypothesis is violated.

where $\eta_{ij} = \max_{m \neq j}(U^*_{im} - U^*_{ij}) < 0$ (Bourguignon et al. 2007). Equation (2) implies that the i^{th} farmer will adopt package j to maximize his expected profit if package j provides greater expected profit than any other package $m \neq j$, that is, if $\eta_{ij} = \max_{m \neq j}(U^*_{ij} - U^*_{im}) > 0$.

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

$$P_{ij} = \Pr(\eta_{ij} < 0 \mid X_i) = \frac{\exp(X_i \beta_j)}{\sum_{m=1}^{J} \exp(X_i \beta_m)}. \tag{3}$$

The parameters of the latent variable model can be estimated by maximum likelihood.

In the second stage of multinomial ESR, the relationship between the outcome variables and a set of exogenous variables Z (plot, household and location characteristics) is estimated for the chosen package. In our SAPs specification (Table 1), the base category, non-adoption of SAP (i.e., $R_0V_0T_0$), is denoted as j = 1. In the remaining packages (j = 2, … , 8), at least one SAP is used. The outcome equation for each possible regime j is given as:

$$\begin{cases} \text{Regime } 1: Q_{i1} = Z_i \alpha_1 + u_{i1} & \text{if } I = 1 \\ \vdots \qquad \vdots \\ \vdots \qquad \vdots \\ \text{Regime J}: Q_{iJ} = Z_i \alpha_J + u_{iJ} & \text{if } I = J \end{cases} \tag{4}$$

where $Q_{ij}'s$ are the outcome variables of the i^{th} farmer in regime j, and the error terms (u's) are distributed with $E(u_{ij} | X, Z) = 0$ and $\operatorname{var}(u_{ij} | X, Z) = \sigma^2_j$. Q_{ij} is observed if, and only if, package j is used, which occurs when $U^*_{ij} > \max_{m \neq j}(U^*_{im})$. If the ε's and u's are not independent, OLS estimates in (4) will be biased. A consistent estimation of α_j requires inclusion of the selection correction terms of the alternative choices in (4). The DM model assumes the following linearity assumption:

$$E(u_{ij} \mid \varepsilon_{i1} \ldots \varepsilon_{iJ}) = \sigma_j \sum_{m \neq j}^{J} r_j (\varepsilon_{im} - E(\varepsilon_{im})),$$

with $\sum_{m=1}^{J} r_j = 0$ (by construction, the correlation between $u's$ and $\varepsilon's$ sums to zero).

Using this assumption, the equation of the multinomial ESR in (4) is specified as:

$$\begin{cases} \text{Regime } 1: Q_{i1} = Z_i\alpha_1 + \sigma_1\hat{\lambda}_1 + \omega_{i1} \quad \text{if } I = 1 \\ \vdots \qquad\qquad \vdots \\ \text{Regime J}: Q_{iJ} = Z_i\alpha_J + \sigma_J\hat{\lambda}_J + \omega_{iJ} \quad \text{if } I = J \end{cases} \tag{5}$$

where σ_{j} is the covariance between $\varepsilon's$ and $u's$, and λ_j is the inverse Mills ratio computed from the estimated probabilities in (3) as follows:

$$\lambda_j = \sum_{m \neq j}^{J} \rho_j \left[\frac{\hat{\mathrm{P}}_{im} \ln(\hat{\mathrm{P}}_{im})}{1 - \hat{\mathrm{P}}_{im}} + \ln(\hat{\mathrm{P}}_{ij}) \right]$$

where ρ is the correlation coefficient of $\varepsilon's$, 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 package. The standard errors in (5) are bootstrapped to account for the heteroskedasticity arising from the generated regressor (λ_j).

3.2. Estimation of average treatment effects

The above framework can be used to examine the average treatment effect (ATT) by comparing the expected outcomes of adopters with and without adoption. The challenge of impact evaluation using observational data is to estimate the counterfactual outcome, which is the outcome the adopters could have earned had they not adopted the packages. Following Carter and Milon (2005) and Di Falco and Veronesi (2011), we compute the ATT in the actual and counterfactual scenarios as follows;[6]

Adopters with adoption (actual adoption observed in the sample):

$$\begin{cases} E(Q_{i2} \mid I = 2) = Z_i\alpha_2 + \sigma_2\lambda_2 & \text{(6a)} \\ \vdots \qquad\qquad \vdots \\ E(Q_{iJ} \mid I = J) = Z_i\alpha_J + \sigma_J\lambda_J & \text{(6b)} \end{cases}$$

Adopters, had they decided not to adopt (counterfactual):

$$\begin{cases} E(Q_{i1} \mid I = 2) = Z_i\alpha_1 + \sigma_1\lambda_2 & \text{(7a)} \\ \vdots \qquad\qquad \vdots \\ E(Q_{i1} \mid I = J) = Z_i\alpha_1 + \sigma_1\lambda_J & \text{(7b)} \end{cases}$$

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[6] The effect of treatment on untreated (ATU) can also be computed using this framework by comparing the expected outcome of non-adopters with non-adoption with the expected outcome of non-adopters had they adopted the packages; however, we did not report this to save space.

These expected values are used to derive unbiased estimates of the ATT. The ATT is defined as the difference between (6a) and (7a) or (6b) and (7b). For instance, the difference between (6a) and (7a) is given as:

$$ATT = E[Q_{i2} \mid I = 2] - E[Q_{i1} \mid I = 2] = Z_i(\alpha_2 - \alpha_1) + \lambda_2(\sigma_2 - \sigma_1). \qquad (8)$$

The first term on the right-hand side of equation (8) represents the expected change in adopters' mean outcome, if adopters' characteristics had the same return as non-adopters, i.e., if adopters had the same characteristics as non-adopters. The second term (λ_j) is the selection term that captures all potential effects of difference in unobserved variables.

4. The Empirical Specification

The specification of our empirical model is based on a review of theoretical work and previous similar empirical adoption and impact studies (D'Souza et al., 1993; Fuglie, 1999; Neill and Lee, 2001; Lee, 2005; Bandiera and Rasul, 2006; Knowler and Bradshaw, 2007; Di Falco et al., 2010; Wollni et al., 2010; Kassie et al., 2010, 2011; Kasem and Thapa, 2011). According to this literature, many factors affect adoption and thus affect our outcome variables. These factors include farm characteristics (soil depth, slope, fertility, plot distance to dwelling); social capital, governance and information (membership in farmers' association, number of grain traders that farmers know in their vicinity, number of blood relatives in and outside the village, extension contacts, and household confidence in skill of extension workers); shocks and social insurance (self-reported rainfall shocks, plot level crop production disturbances, and farmers' reliance on government support during crop failure); resource constraints and market access (farm size/livestock, farm equipment ownership, distance to main market and input dealers, and access to credit); household characteristics (family size, household head education, spouse education, gender, and age); and geographic location (which can be captured using district dummies).

Below, we focus on describing those variables that are not common in the adoption and impact literature. A detailed description and hypothesis on the role of these factors in influencing SAPs adoption decisions of farmers can be found in Kassie et al. (2012) and Teklewold et al. (in press).

The rainfall disturbance variable is based on respondents' subjective rainfall[7] satisfaction in terms of timeliness, amount and distribution. The individual rainfall index was constructed to measure the farm-specific experience related to rainfall in the preceding three seasons, based on such questions as whether rainfall came and stopped on time, whether there was enough rain at the beginning of and during the growing season, and whether it rained at harvest time. Responses to each of these questions (either yes or no) were coded as favorable or unfavorable rainfall outcomes, and averaged over the number of questions asked (five questions) so that the best outcome would be equal to one and the worst equal to zero. Plot-level disturbance is captured by the most common stresses affecting crop production: attacks by pests and diseases, waterlogging and drought, and frost and hailstorm stress.

In this study, credit-constrained farmers are defined as those who need credit but are unable to get it (30%). Accordingly, credit-unconstrained farmers are those who do not need credit (40%) as well as those who need it and are able to get it (30%).

We also control for the possible role of farmers' perceptions of government assistance, by including a dummy variable that takes the value of one if the farmers beleive that they can rely on government support during crop failure. We distinguish three forms of social capital and networks: a household's relationship with rural institutions in the village; a household's relationship with trustworthy traders; and a household's kinship network. Such classification is important because different forms of social capital and networks may affect the adoption of SAPs in various ways. Examples include information sharing, stable market outlets, labor sharing, the relaxation of liquidity constraints, and mitigation of risks.

5. Empirical Results

5.1. Factors explaining the adoption of a SAPs package

The results from the multinomial logit model are presented in Table 4.[8] The base category is non-adoption ($R_0V_0T_0$), where results are compared.

[Table 4 here]

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[7] Actual rainfall data are preferable, but reliable data that are in-season and village-specific are scarce in most developing countries, including Ethiopia.

[8] The model is estimated using the stata selmlog routine (Bourguignon et al., 2007).

The model fits the data reasonably well. The Wald test that all regression coefficients are jointly equal to zero is rejected [$\chi^2(266) = 956.44$; $p = 0.000$]. The results show that the estimated coefficients differ substantially across the alternative packages.

The spouse's (women's) education level has a positive impact on the adoption of the improved variety–conservation tillage package ($R_0V_1T_1$). There is a strong correlation between the adoption of package $R_1V_1T_1$ and family size and age of the household head: increasing for family size but decreasing for household age.

Farm size is positively related to SAPs packages containing all SAPs ($R_1V_1T_1$), perhaps because of demand for labor-saving technologies. A similar result was found by Fuglie (1999) in the US. However, adoption of package $R_1V_1T_1$ is more likely to be by small farmers, probably because smaller farmers tend to achieve food security by sustainably intensifying production.

All social capital and network variables have positive impacts on adoption of most SAPs packages. Farmers in developing countries face imperfect markets, including transactions costs and scarce information. For instance, Ethiopian farmers have inadequate information about insurance markets. Under these circumstances, social networks could facilitate the exchange of information, enable farmers to access inputs on schedule, and overcome credit constraints. This finding suggests that, in order to enhance the adoption of SAPs, local rural institutions and service providers need to be supported, because they can effectively assist farmers by providing credit, inputs, information, and stable market outlets.

Adoption of $R_0V_1T_0$ (only improved seeds) is more common by farmers who trust in government support when crops fail, probably because the benefit of new technologies (i.e., modern seeds) is uncertain and farmers may need insurance to adopt new technologies. The results also reveal that more highly-skilled extension agents enhance the likelihood of adoption of packages $R_0V_1T_0$, $R_0V_0T_1$, $R_0V_1T_1$, and $R_1V_1T_1$. This could be because a package combining modern seeds and conservation tillage is relatively knowledge-intensive and requires considerable management input. This underscores the importance of upgrading the skills of extension workers to speed up adoption of SAPs.

The results further indicate the importance of rainfall and plot level shocks in determining the adoption of SAPs packages. The probability of adoption of $R_1V_0T_0$ is high in areas/years where rainfall is perceived to be favorable in terms of timing, amount and distribution. Similarly, adoption of $R_1V_1T_1$, $R_1V_1T_0$, and $R_1V_0T_0$ is negatively and significantly influenced by waterlogging stress. The incidence of pests and diseases positively influences the adoption of packages $R_0V_0T_1$, $R_1V_1T_0$, $R_1V_0T_1$ and $R_0V_1T_1$. Finally, plot characteristics also condition the adoption of different packages, suggesting the importance of considering these characteristics in promoting SAP packages.

5.2. Average adoption effects for a combination of SAPs

The second stage regression estimates are not reported to conserve space but are available upon request from the authors. However, it is worth mentioning that we used logarithmic transformed dependent variables based on the Box-Cox test functional specification test.[9] The Box-Cox test statistic rejects the null hypothesis that the goodness of fit of the linear dependent variables (levels) and the logarithmic dependent variables (logs) are the same. In all the regression equations, the estimated values of Chi-square exceed the critical value suggesting the logarithmic transformations better fit the data. The detail statistics for each outcome variable is available from the authors. It is also worth noting that many of the coefficients on the selection correction terms are significant. This suggests that adoption of SAPs packages will not have the same effects on non-adopters, should they choose to adopt, as it would on adopters.

Table 5 presents the unconditional and conditional average effects of adoption of a combination of SAPs. The unconditional average effects indicate that adopters of any SAPs packages earn more maize income, on average, than non-adopters. The same is true for other outcome variables, except that non-adopters use more N fertilizer under package $R_0V_0T_1$. However, this simple comparison is misleading because it does not account for both observed and unobserved factors that may influence outcome variables.

[Table 5 here]

To estimate the true average adoption effects for households that did adopt, the outcome variables of farm households who adopted SAPs packages are compared with the outcome variables if the farm households had not adopted. We do this by applying equation (8). We found that, in almost all cases, adoption of a combination of SAPs provides more maize income compared to adopting each SAP in isolation. Farmers obtained a higher income when system

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[9] We thank the anonymous reviewer for suggesting carrying out this test.

diversification and conservation tillage practices were combined with improved seeds. This was the case whether the farmer adopted all three SAPs, adopted diversification plus improved seeds, or adopted tillage plus improved seeds. The largest income effect (5.58 thousand birr/hectare) is from adoption of package $R_1V_1T_1$.

With regard to input use, we found that, for farmers who adopted package $R_1V_1T_0$, the average labor demand both for females and males is significantly higher than it would have been if the adopters had adopted $R_0V_0T_0$. However, the average N and pesticide use are not significantly affected. This is probably because system diversification reduces farmers' use of N, due to N fixation by the legume crops, and from using pesticides, because diversification controls pests, weeds, and disease. On the other hand, adoption of $R_0V_0T_1$ and $R_0V_1T_1$ significantly increased pesticide application and labor demands, while significantly reducing the average N application. The decrease in N application is greater when farmers use traditional maize varieties ($R_0V_0T_1$) and even further under package $R_1V_0T_1$ (system diversification combined with conservation tillage) without significantly affecting the average maize income, pesticides use, and households' labor demand. Similarly, adoption of system diversification with traditional varieties ($R_1V_0T_0$) does not significantly affect the average N and pesticide use and female labor, but reduces the male workload. The average N and pesticide use and labor demand significantly increase with adoption of $R_1V_1T_1$ and $R_0V_1T_0$. This is probably due to the complementarity between improved maize variety adoption and fertilizer and pesticides through the increase in agrochemical use because of adoption of package $R_0V_1T_0$. Without soil and water conserving technologies, this may jeopardize agricultural sustainability in the long run. Furthermore, the use of more pesticides in the package that contains improved seed is probably because farmers would like to avoid risk, as high yielding varieties may be susceptible to pest outbreaks (Jhamtani, 2011).

The above results have the following implications. First, adoption of SAPs increases maize income, and the highest payoff is achieved when SAPs are adopted in combination rather than in isolation. Second, farmers appear to properly credit N fixed by legume crops and to consider the soil fertility effects of conservation tillage, because N fertilizer use is either reduced or statistically insignificant when system diversification is used, whether in combination or isolation. Third, the notion that conservation tillage may increase pesticide application and labor demand to compensate for less tillage (Fuglie, 1999) is observed in this study; pesticide use and labor demand increase in the package that includes conservation tillage. Fourth, in most cases, changes in pesticide use and the change in male and female labor demand were statistically insignificant in the package that contains system diversification. This is perhaps because system diversification helps to maintain soil biodiversity, which can reduce pest and weed infestations that otherwise must be controlled by pesticides and/or additional labor (Tilman et al., 2002; Hajjar et al., 2008). However, this effect of system diversification is outweighed when it is used in combination with modern seeds and conservation tillage ($R_1V_1T_1$). Fifth, adoption of packages has different effects on male and female labor time allocation. In nearly all cases, adoption of SAP packages leads to more time spent working on the farm for females that for males. This may negatively affect larger households by diverting time from other activities such as food preparation and childcare, as women are usually responsible for routine care of the household. Sixth, promoting system diversification and conservation tillage, either in combination or isolation, has an important positive long-term environmental implication without an economic trade-off.

6. Concluding Remarks

Adoption of SAPs and the effects of adoption have received considerable attention from development economists. Prior research focuses on specific practices; less information is available on simultaneous adoption of multiple and interdependent SAPs and their impacts. In this paper, we evaluate the adoption of multiple SAPs and their impacts on maize income, agrochemicals, and labor input intensity in maize–legume farming systems of Ethiopia. A multinomial ESR is used to account for self-selection in choosing combined and potentially interdependent packages of SAPs and the interactions between them.

The multinomial logit selection model results revealed that the likelihood of adoption of a package of SAPs is influenced by observable plot, household and village characteristics. These include rainfall and plot level disturbances; soil characteristics and distance of the plot from home; social capital in the form of access and participation in rural institutions; the number of relatives and traders known by the farmer; market access; wealth, age, spouse education and family size; the farmer’s expectations of government support in case of crop failure; and confidence in the skill of public extension agents. These results can be used to inform and target policies aimed at increasing adoption rates of multiple and interdependent SAPs. For example, the correlation of spouse's education with increased adoption of conservation tillage and improved seeds suggests that female education can be an important driver of adoption of sustainable agricultural practices in Ethiopia. Similarly, the significant role of social capital suggests the need for establishing and strengthening local institutions and service providers to accelerate and support adoption of SAPs. The effects of weather-related risks are also important for enhancing SAPs adoption and underscore the need to provide climatic information, not only in terms of rainfall amount but also its timing and distribution. Furthermore, the use of SAPs is positively associated with the farmer's expectation of timely government support during crop failure and with confidence in the skill of extension agents. These suggest a number of supplementary policy measures: investment in public safety-net programs (public insurance) and risk-protection mechanisms, and the need for technically capable extension service providers.

With regard to the results of adoption effects, adoption of multiple SAPs significantly increases maize income. The package that contains all improved SAPs (cropping system diversification, conservation tillage and improved seed varieties) provides the highest income. This has important policy implications. Efforts to improve productivity and food security should combine improved seed varieties with appropriate agronomic practices that increase the profitability of investments in seed-based technologies while enhancing ecosystem resilience and sustainability. Adoption of the combined SAP packages has a positive effect on N and pesticide application and male and female on-farm labor. However, it also appears that system diversification or conservation tillage, or both, when used with traditional seed varieties, enables farmers to reduce N without significantly affecting income. In addition, comparing the change in pesticide use for modern and traditional maize varieties reveals that pesticide application would not significantly increase when conservation tillage and system diversification are jointly used with traditional maize varieties. Conservation tillage requires application of some herbicides (e.g. glyphosate) to kill weeds before planting under reduced or zero till systems. This may have some undesirable environmental effects, but will progressively be reduced as the weed pressure decreases with retention of residues on the field. This suggests that policymakers, researchers and extension agents should use alternative options to design win–win strategies to address household food security and minimize the use of non-renewable external off-farm inputs (pesticides and fertilizers) that harm the environment.

Acknowledgements

This research was supported by the Australian Center for International Agricultural Research (ACIAR) and the Australian International Food Security center(AIFSC) under the CIMMYT-led SIMLESA project for Sustainable Intensification of Maize-Legume Cropping Systems in Eastern and Southern Africa. Additional financial and logistic support for this study from EIAR (Ethiopian Institute of Agricultural Research) and Sida (Swedish International Development and Cooperation Agency) through the Environmental Economics Unit, University of Gothenburg is also gratefully acknowledged. The paper benefited from the comments of participants in the Department of Economics Seminar Series, University of Gothenburg; the 19th Annual Conference of the European Association of Environmental and Resource Economists, Prague, June 27–30, 2012; and the 28th Triennial Conference of the International Association of Agricultural Economists (IAAE), 18–24, August, 2012, Brazil. We would also like to thank the two anonymous reviewers for their constructive comments.

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Table 1. SAPs packages used on maize plots

Choice (*j*)	Binary triplet (Package)	Cropping system diversification (R)		Improved variety (V)		Conservation tillage (T)		Frequency (%)
		R_1	R_0	V_1	V_0	T_1	T_0	
1	$R_0V_0T_0$		√		√		√	25.40
2	$R_1V_0T_0$	√			√		√	5.43
3	$R_0V_1T_0$		√	√			√	24.79
4	$R_0V_0T_1$		√		√	√		12.03
5	$R_1V_1T_0$	√		√			√	8.00
6	$R_1V_0T_1$	√			√	√		4.46
7	$R_0V_1T_1$		√	√		√		14.47
8	$R_1V_1T_1$	√		√		√		5.43

Note: The binary triplet represents the possible SAPs combinations. Each element in the triplet is a binary variable for a SAP: system diversification (R), modern seed (V) or conservation tillage (T). Subscript 1 = adoption and 0 = otherwise.

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

	Cropping system diversification (R)	Conservation tillage (T)	Modern maize seeds (V)
$P(Y_k = 1)$	23.3	36.4	52.5
$P(Y_k = 1 \mid Y_R = 1)$	100.0	49.5**	57.6**
$P(Y_k = 1 \mid Y_T = 1)$	27.1**	100.0	54.8
$P(Y_k = 1 \mid Y_V = 1)$	25.5*	38.0	100.0
$P(Y_k = 1 \mid Y_R = 1, Y_T = 1)$	100.0	100.0	54.9
$P(Y_k = 1 \mid Y_R = 1, Y_V = 1)$	100.0	40.5	100.0
$P(Y_k = 1 \mid Y_T = 1, Y_V = 1)$	27.1**	100.0	100.0

Note: Y_k is a binary variable representing the adoption status with respect to choice *k* (*k* = system diversification (R), conservation tillage (T) or modern maize seeds (V)); *, ** and *** indicate a statistically significant difference at 10, 5 and 1%, respectively. The comparison is between unconditional and conditional probabilities for each SAP.

Table 3. Definitions and summary statistics of the variables used in the analysis

Variables	Variable description	Mean values for SAPs package								Mean of all SAPs	SD of all SAPs
		$R_0V_0T_0$	$R_1V_0T_0$	$R_0V_1T_0$	$R_0V_0T_1$	$R_1V_1T_0$	$R_1V_0T_1$	$R_0V_1T_1$	$R_1V_1T_1$		
	Household characteristics										
FAMLYSIZE	Family size (number)	6.70	6.22*	7.02**	6.87	6.39	6.33	7.14**	7.43**	6.85	2.82
MALEHEAD	1= if the head is male	0.89	0.90	0.95***	0.91	0.94	0.86	0.92	0.90	0.92	–
AGE	Age of the head	42.58	41.28	40.67**	41.80	39.42***	42.15	43.49	39.24**	41.64	13.34
EDUCATHEAD	Years of education of the head	3.23	3.79*	3.52	2.99	3.79**	3.30	3.74**	3.24	3.43	3.43
EDUCATSPOUS	Years of education of the spouse	1.08	1.74***	1.22	1.19	1.80***	1.49**	2.17***	1.36	1.42	2.85
	Resource constraints and market access										
FARMSIZE	Farm size, ha	1.88	1.92	2.10	2.07	1.80	1.80	2.40**	1.82	2.00	2.48
ASSETVALUE	Total value of assets, ‘000 ETB	15.49	12.18*	16.19	19.90**	18.23	23.09**	29.79***	32.17***	19.64	50.48
OTHERINCOM	1= the household earns other income and transfers	0.66	0.82**	0.66	0.59*	0.66	0.67	0.59**	0.69	0.65	–
TLU	Livestock herd size (in tropical livestock unit)	5.17	4.23*	5.71***	5.51	5.39	5.21	5.59**	5.32	5.54	6.05
CREDIT	1=credit constrained (credit is needed but unable to obtain)	0.32	0.33	0.28	0.29	0.24*	0.21**	0.23**	0.30	0.28	–
MEANSTRANS	1=walking to market as means of transportation	0.49	0.49	0.52	0.43	0.41	0.40	0.28***	0.29***	0.44	–
WALKMKT	Walking distance to village markets, minutes	27.96	19.06**	29.01	28.37	22.44*	20.47**	30.11	24.49	27.13	37.31
WALKINPUT	Walking distance to input markets, minutes	61.80	54.58	59.95	63.14	55.51	62.96	57.39	57.67	59.30	55.75
	Social capital, governance and information										
TOTALMEMBER	Number of associations the household belongs to	2.13	1.91**	2.03*	2.16	2.06	2.18	1.91***	2.11	2.06	1.07
INPUTMEMBER	1= member of input/seed/marketing cooperatives	0.18	0.15	0.21	0.25**	0.32***	0.25	0.36***	0.35***	0.25	–
RELATIVE	Number of relatives living inside and outside the village	8.54	9.66	10.29***	11.48***	10.23**	11.86***	9.68*	13.39***	10.10	11.36
TRUSTTRADER	Number of grain traders that farmers know and trust	1.95	2.98***	2.78***	2.31*	3.02***	2.40	2.40**	2.44**	2.46	4.01
FREQEXTCONT	Frequency of extension contact, days/year	14.47	18.38	16.57	19.35	13.27	16.74	18.55	18.35	16.64	43.59
CONFDNT	1=confident of skills of extension workers	0.78	0.88**	0.83*	0.83	0.78	0.78	0.81	0.90***	0.82	–
	Shocks and social insurance										
RAININDEX	Rainfall index (1= best)	0.48	0.57**	0.50*	0.54***	0.59***	0.54**	0.55***	0.53*	0.52	0.30
PESTSTRES	1=pest and disease stress	0.07	0.12	0.09	0.14***	0.15***	0.18***	0.18***	0.12	0.12	–
WATRLOGG	1=water logging/drought stress	0.30	0.16***	0.25	0.19***	0.14***	0.18**	0.18***	0.20*	0.22	–
FROSTSTRES	1=frost/hailstorm stress	0.08	0.10	0.06	0.11	0.03*	0.05	0.04*	0.02*	0.06	
RELYGOVT	1=rely on government support in case of crop failures	0.38	0.34	0.55***	0.34	0.37	0.37	0.36	0.46	0.42	–
	Plot characteristics										
PLOTDIST	Plot distance from home, minutes	11.86	6.82**	12.91	8.37**	10.04	12.08	11.99	10.90	11.33	27.50
RENTD	1=rented plot	0.11	0.18*	0.19***	0.11	0.18**	0.11	0.15	0.11	0.15	–
SHALDEPT	1=shallow depth of soil[a]	0.17	0.26*	0.15	0.23*	0.15	0.32***	0.22	0.31***	0.20	–
MEDMDEPT	1=medium depth of soil	0.36	0.37	0.48***	0.50***	0.47**	0.44	0.47***	0.48**	0.44	–
GOODSOIL	1=good soil quality[b]	0.44	0.39	0.36**	0.41	0.47	0.44	0.32***	0.44	0.40	–
MEDMSOIL	1=medium soil quality	0.50	0.54	0.56	0.49	0.44	0.44	0.54	0.48	0.51	–
FLATSLOP	1=flat plot slope[c]	0.67	0.71	0.62	0.53***	0.69	0.63	0.55***	0.54**	0.62	–
MEDMSLOP	1=medium plot slope	0.28	0.27	0.31	0.42***	0.26	0.30	0.41***	0.42***	0.33	–
MANURE	1=manure was applied in the plot	0.33	0.28	0.26**	0.34	0.25*	0.26	0.18**	0.21**	0.27	–
N	Number of observations	422	89	404	197	131	73	239	89	1,644	

Note: A ttest used to compare the means of explanatory variables between each package of SAPs (adopters) and non-adopters ($R_0V_0T_0$) under the assumption of unequal variance. *, ** and *** denote significance level at 10%, 5% and 1%, respectively;. SD is standard deviation; 1 ETB ≈ 0.058 USD at the time of the survey. [a]Farmer ranked each plot as “deep”, “medium deep” or “shallow”; [b]Farmer ranked each plot as “poor”, “medium” or “good”; [c]Farmer ranked each plot as “flat”, “medium slope” or steep slope”.

Table 4. Parameter estimates of adoption of SAPs packages – multinomial logit selection model

Variables	$R_1V_0T_0$		$R_0V_1T_0$		$R_0V_0T_1$		$R_1V_1T_0$		$R_1V_0T_1$		$R_0V_1T_1$		$R_1V_1T_1$	
	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE.	Coefficient	SE	Coefficient	SE	Coefficient	SE
Household characteristics														
log(FAMLYSIZE)	–0.196	0.386	0.261	0.293	0.209	0.329	–0.161	0.421	0.167	0.481	0.255	0.367	1.566***	0.514
log(AGE)	0.455	0.483	–0.264	0.312	–0.441	0.445	–0.427	0.472	–0.055	0.554	0.311	0.467	–1.367*	0.714
log(EDUCATSPOUS)	0.156	0.197	0.011	0.129	–0.001	0.174	0.088	0.186	0.186	0.208	0.452**	0.187	–0.029	0.206
Resource constraints and market access														
log(FARMSIZE)	–0.146	0.249	0.101	0.140	0.320**	0.152	–0.219	0.169	–0.049	0.198	0.192	0.163	–0.396**	0.190
log(OTHERINCOM)	0.751**	0.336	0.180	0.183	0.145	0.251	0.162	0.275	0.511	0.344	–0.063	0.238	0.435	0.394
CREDIT	–0.032	0.322	–0.336*	0.203	0.082	0.268	–0.476	0.323	–0.377	0.384	–0.175	0.293	–0.087	0.361
MEANSTRANS	0.694**	0.334	0.323*	0.192	–0.018	0.281	0.065	0.295	–0.003	0.330	–0.860***	0.278	–0.432	0.373
log(WALKMKT)	–0.296***	0.108	–0.041	0.065	0.070	0.087	–0.170*	0.099	–0.060	0.117	0.113	0.081	–0.061	0.112
Social capital and extensions														
INPUTMEMBER	–0.238	0.401	–0.081	0.227	0.177	0.311	0.584**	0.282	0.770**	0.380	0.610**	0.287	1.148***	0.341
RELATIVE	0.006	0.013	0.010	0.009	0.033***	0.010	0.012	0.014	0.038***	0.012	0.016	0.011	0.037***	0.012
TRUSTTRADER	0.103***	0.029	0.062***	0.023	0.042	0.031	0.084**	0.037	0.062*	0.036	0.075**	0.033	0.052	0.041
CONFDNT	0.752	0.484	0.400*	0.221	0.710**	0.315	0.100	0.316	0.359	0.345	0.514*	0.307	1.149**	0.495
Shocks														
RAININDEX	1.146*	0.592	–0.241	0.343	–0.120	0.444	0.268	0.533	–0.337	0.586	–0.623	0.464	–0.581	0.544
PESTSTRES	0.492	0.473	0.140	0.313	0.653*	0.344	0.654*	0.377	1.013**	0.411	0.781**	0.328	0.102	0.405
WATRLOGG	–0.922**	0.362	–0.158	0.227	–0.244	0.285	–0.882**	0.393	0.037	0.444	–0.216	0.321	–0.637*	0.372
RELYGOVT	–0.127	0.309	0.627***	0.188	0.012	0.239	–0.118	0.305	0.238	0.308	0.049	0.224	0.483	0.299
Plot characteristics														
log(PLOTDIST)	–0.151	0.114	0.063	0.073	–0.156*	0.088	0.002	0.109	–0.185	0.160	0.066	0.089	–0.081	0.134
SHALDEPT	0.594*	0.313	0.298	0.256	0.395	0.311	–0.206	0.357	0.532	0.396	0.205	0.302	1.127***	0.411
MEDMDEPT	0.417	0.295	0.435**	0.203	0.580**	0.273	0.721**	0.284	0.669*	0.368	0.375	0.286	0.761**	0.377
GOODSOIL	–0.157	0.540	0.664**	0.327	–0.771*	0.399	–0.307	0.488	–0.241	0.519	–1.353***	0.372	–0.201	0.537
MEDMSOIL	–0.083	0.562	–0.409	0.305	–0.832**	0.390	–0.693	0.490	–0.436	0.506	–1.044***	0.348	–0.127	0.513
FLATSLOP	0.910	0.871	–0.148	0.362	0.095	0.436	0.608	0.520	0.416	0.590	1.232***	0.465	0.037	0.669
MEDMSLOP	0.818	0.859	–0.248	0.353	0.428	0.417	0.107	0.549	0.192	0.564	1.138**	0.461	0.615	0.637
MANURE	–0.415	0.298	–0.263	0.176	–0.001	0.205	–0.533*	0.287	–0.650*	0.332	–0.744***	0.221	–0.669**	0.306
CONSTANT	–6.079***	2.345	–0.575	1.425	–0.224	1.952	0.204	2.108	–1.460	2.496	–1.311	2.108	0.310	2.841
Joint-significance of location variables: χ^2 (7)	16.39**		27.70***		19.61***		18.39***		30.56***		28.91***		30.04***	

Number of observations = 1,614; Wald χ^2 = 970.72; p > χ^2 = 0.000

Note: SE is robust standard errors; *, ** and *** indicate statistical significance at 10%, 5% and 1% level, respectively; $R_0V_0T_0$ is the reference category (non-adoption). Other non-significant variables include: MALEHEAD, EDUCATHEAD; ASSETVALUE; TLU; WALKINPUT; FREQEXTCONT; FROSTSTRES; RENTD.

Table 5. The average effect of adoption of SAPs package using multinomial ESR

Adoption effects	Package	Outcome				
		Maize income (Birr/ha)	N application (Kg/ha)	Pesticide application (l/ha)	Labor (labor days/ha)	
					Women	Men
Unconditional average effects	$R_1V_0T_0$	5,924.00***	101.66***	2.19***	0.411	4.01***
		(721.76)	(13.96)	(0.37)	(0.53)	(0.99)
	$R_0V_1T_0$	2,751.24***	3.77***	0.89***	3.18***	2.62***
		(135.84)	(1.14)	(0.03)	(0.37)	(0.36)
	$R_0V_0T_1$	3,929.43***	–12.18***	2.49***	9.26***	6.85***
		(207.32)	(1.06)	(0.10)	(0.42)	(0.55)
	$R_1V_1T_0$	5,858.69***	31.80***	0.16***	2.52***	0.03
		(325.28)	(3.21)	(0.04)	(0.42)	(0.46)
	$R_1V_0T_1$	7,324.07***	54.89***	21.60***	12.50***	24.87***
		(584.67)	(7.51)	(3.77)	(1.52)	(3.07)
	$R_0V_1T_1$	2,795.68***	–1.19	1.25***	3.83***	1.81***
		(187.57)	(1.16)	(0.04)	(0.41)	(0.48)
	$R_1V_1T_1$	6,822.82***	332.82***	2.83***	13.69***	2.23***
		(253.74)	(50.20)	(0.19)	(0.49)	(0.50)
Average treatment effects on treated (ATT)	$R_1V_0T_0$	1,892.43***	9.45	0.59	–0.63	–3.32**
		(819.78)	(9.31)	(0.58)	(1.74)	(1.94)
	$R_0V_1T_0$	2,823.06***	3.78**	1.04***	3.13***	1.71***
		(269.44)	(2.29)	(0.06)	(0.62)	(0.61)
	$R_0V_0T_1$	2,349.90***	–13.92***	2.95***	2.97***	3.11***
		(376.70)	(2.89)	(0.49)	(1.06)	(1.26)
	$R_1V_1T_0$	4,506.65***	7.81	0.01	6.08***	2.36**
		(752.39)	(6.72)	(0.13)	(1.33)	(1.33)
	$R_1V_0T_1$	497.54	–19.95***	3.42	1.57	3.61
		(903.52)	(5.69)	(3.21)	(2.54)	(3.44)
	$R_0V_1T_1$	2,840.85***	–5.60**	0.84***	1.60**	0.59
		(405.59)	(3.57)	(0.09)	(1.05)	(0.99)
	$R_1V_1T_1$	5,579.47***	15.27*	1.49***	10.12***	4.99***
		(745.39)	(10.65)	(0.30)	(1.73)	(1.99)

Note: Standard errors are in parenthesis; *, ** and *** indicate statistical significance at 10%, 5% and 1% level, respectively.