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Understanding the adoption of a portfolio of sustainable intensification practices in eastern and southern Africa

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ABSTRACT

This paper explores smallholder farmers' adoption decisions of multiple sustainable intensification practices (SIPs) in eastern and southern Africa. We develop a multivariate probit model using plot-level data gathered from maize–legume farming systems in Ethiopia, Kenya, Malawi, and Tanzania. We find that some practices used in maize production are complementary while others are substitutable. The adoption of SIPs is influenced by social capital and networks, quality of extension services, reliance on government support during crop failure, incidence of pests and diseases, resource constraints, tenure security, education, and market access. The results provide insight into the further efforts needed to encourage greater adoption of SIPs.

Introduction

The core pillars for Asia's green revolution were the widespread adoption of high-yielding varieties and fertilizers, accompanied by public support for irrigation. However, these core technologies by themselves are inadequate to sustain agricultural productivity. Indeed, such agricultural intensification may generate negative environmental externalities such as groundwater depletion, soil fertility degradation, and chemical runoff (see, e.g., Pingali and Rosegrant, 1994; Pingali, 2012). Due attention should be paid to the agricultural resource base and a healthy agro-ecosystem as the basis for sustainable agricultural intensification. Yet often, agricultural intensification discussions focus on the role of seeds and fertilizers without concomitant articulation of complementary agronomic practices. There is a need to more formally and deliberately support and promote the inclusion of agronomic and natural resources management practices as critical elements of a balanced agricultural sustainable intensification process. Sustainable intensification practices (SIPs) aim to enhance the productivity and resilience of agricultural production systems while conserving the natural resource base (Pretty et al., 2011; Godfray et al., 2010; The Montpellier Panel, 2013; Tilman et al., 2011). Recent empirical evidence (see Teklewold et al., 2013; Kassie et al., 2014) shows that combinations of SIPs provide higher net maize income and either reduce or keep constant input use than when only single practices are adopted. Given the confirmed economic benefits of joint implementation of the SIPs studied here, why then do we observe low adoption rates at farm level? Which demographic, social, economic or institutional factors prevent farmers from adopting these clearly superior practices (and their combinations)?

The purpose of this research is to improve our understanding of farmers' adoption decisions of SIPs in eastern and southern Africa (ESA). Secondly we investigate which SIPs are complementary and which are substitutable, information that is crucial to understanding technology adoption processes. These objectives are achieved by applying a multivariate probit model using plot and household-level data gathered from Ethiopia, Kenya, Malawi, and Tanzania. The SIPs examined in this study are minimum tillage; improved maize varieties; crop diversification (i.e., legume–maize intercropping and crop rotations); soil and water conservation practices; inorganic fertilizers, and animal manure.

Our research is carried out against the backdrop of low agricultural productivity in ESA due to reliance on rain-fed agriculture, poverty and declining soil fertility linked to soil erosion and nutrient depletion (Morris et al., 2007). Improved varieties and agrochemical inputs have helped to increase crop yields elsewhere (Tilman et al., 2002; Evenson and Gollin, 2003) – but have been less

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successful in ESA. Furthermore, for long run sustainability, their potential cannot be realized when soils are depleted of plant nutrients or the natural resource base is being degraded (Sanchez, 2002). Adding to the urgency of the situation, many farmers in ESA indeed lack the capital to purchase adequate amounts of agrochemical inputs, emphasizing the need for a broader approach to agricultural sustainable intensification.

Therefore, in recent years, there has been increased emphasis on sustainable intensification to utilize the existing land to produce greater yields, and to achieve the twin goals of positive economic and environmental outcomes as a surer basis for long-term agricultural development and welfare improvement (Godfray et al., 2010; Pretty et al., 2011; The Montpellier Panel, 2013; Tilman et al., 2011). The key issue is that more food needs to be produced on existing agricultural land while safe-guarding its productive capacity. Bringing new land into cultivation is becoming increasingly constrained due to rising population pressure, competition for land from other human activities such as urbanization, and the need to protect remaining uncultivated areas such as forests for carbon storage and preservation of the environment. From this perspective, an integrated adoption of SIPs has the potential to increase yields, improve nutritional quality, and reduce poverty. Adoption of SIPs can also increase farmers' ability to adapt to climate change and variability and can bring about wider environmental gains such as increased soil health (soil fertility and soil conservation) and reduced deforestation due to reduction in agricultural land expansion (Woodfine, 2009; Snapp et al., 2010; Jhamtani, 2011).

Economic models of agricultural technology adoption often analyze the decision to adopt a single technology/practice,[1] with scant attention to the analysis of multiple technologies whose adoption and economic impact are potentially inter-related and could provide better outcomes when they are adopted jointly. Limited attention has also been given to adoption analysis of agronomic and natural resource management practices. In order to successfully raise crops (and livestock) within their constrained environment, farmers adopt multiple technologies jointly, both as complements and as substitutes.

Recent studies in Ethiopia and Malawi (Teklewold et al., 2013; Kassie et al., 2014) using similar data as used in this paper found that adopting a combined set of SIPs provided more maize net income than adopting them individually. Complementarities among new technologies can indeed increase income and stimulate adoption of multiple technologies (Yu et al., 2012). Yu et al. (2012) showed that as the number of bundled/combined technologies increases, they are increasingly likely to complement one another, even if subsets are substitutes when viewed in isolation. These findings suggest that farmers that can (eventually) implement combinations of technologies at once can take advantage of complementarities that would not occur if they adopted only a subset of those technologies. Analysis without controlling for technology interdependence may therefore under- or over-estimate the influence of various factors on the decision to adopt (Wu and Babcock, 1998; Khanna, 2001) and the impacts of adoption.

This paper addresses this gap by jointly analyzing multiple technology adoption decisions including agronomic management practices (legume–maize intercropping, rotations, minimum tillage, and manure).

The rest of this paper is organized as follows: the next section outlines the conceptual framework, model specification and econometric strategy. Section "Study areas, data and sampling procedure" describes the study areas and the data sources; section "Descriptive statistics: dependent and explanatory variables" presents the dependent and explanatory variables used and the associated descriptive statistics. Section "Results and discussion" presents the modeling results including conditional adoption probabilities; and section "Conclusions and implications" concludes by summarizing and outlining the policy messages emanating from this analysis.

[1] This is equivalent to assuming adoption of technologies is independent or substitute.

Conceptual framework, model specification and estimation strategy

We apply a multivariate probit (MVP) model in this study for modeling the multivariate adoption decision in the presence of adoption interdependence. The MVP recognizes the correlation in the error terms of adoption equations and estimates a set of binary probit models (in our case six probit models) simultaneously. The application of univariate probit or logit models is inefficient when technologies are inter-related since univariate models ignore the correlation in the error terms of adoption equations (Dorfman, 1996; Khanna, 2001; Belderbos et al., 2004). This correlation arises because the same unobserved characteristics of farmers could influence the adoption of different SIPs. Crucially, they ignore the fact that the decision to adopt a particular SIP may be conditional on the adoption of another complementary SIP (positive correlation in the error terms of adoption equations) or may be affected by the set of substitutes that are available (negative correlation, Khanna, 2001). Failure to capture interdependence of adoption decisions among different practices may lead to bias and inefficient coefficient estimates (Dorfman, 1996; Wu and Babcock, 1998; Khanna, 2001; Greene, 2008).

The MVP model for multivariate choice decision problems can be represented by two systems of equations. First, a system of equations with latent (unobservable) dependent variables are described by a linear function of a set of observed household (h), plot (p) and location characteristics (X_{hp}) and a multivariate normally distributed stochastic terms (ε_{hp}). Considering all SIPs, each equation in the system can be written as,

$$Y^*_{hpk} = X_{hp}\beta_k + \bar{X}_h\alpha_k + \varepsilon_{hp}, \quad (k = D, T, S, M, V, F) \tag{1}$$

Here Y^*_{hpk} denotes the latent dependent variables which can be represented by the level of expected benefit and/or utility derived from adoption, $\bar{X}$ are vector of the mean value of plot varying covariates (e.g., plot soil fertility, slope, depth, plot distance to residence, etc.) included to control for unobserved heterogeneity following Mundlak (1978) and Wooldridge (2002). Studies that have used this approach using cross-sectional multiple plot observations include Kassie et al. (2008) and Di Falco and Veronesi (2014). D, T, S, M, V, and F denote crop diversification, minimum tillage, soil and water conservation measure, manure use, improved maize varieties, and inorganic fertilizer use, respectively. A household is expected to adopt a given SIP if the expected benefit and/or utility from its adoption implies a higher pay-off compared with non-adoption. The second system of equations describing the observable dichotomous choice variables of households is given as:

$$Y_{hpk} = \begin{cases} 1 & \text{if } Y^*_{hpk} > 0 \\ 0 & \text{otherwise} \end{cases} \tag{2}$$

Y_{hpk} is the adoption of the kth SIP by the hth household on pth plot. In the multivariate model, where the adoption of several SIPs is possible, the error terms jointly follow a multivariate normal distribution (MVN) with zero conditional mean and variance normalized to unity (for identification of the