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Surveys

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 have 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 system 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 system 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.

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 (Bluffstone and Köhlin, 2011; Jhamtani, 2011; Pretty et al., 2011; World Bank, 2007). 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 (Jhamtani, 2011; Lee, 2005; Pretty, 1999; Snapp et al., 2010; Woodfine, 2009). 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 increasing the ability of

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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; Kassie et al., 2010; Lee, 2005; Pretty et al., 2011; Wollni et al., 2010).

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

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 (Altieri, 1999; Di Falco et al., 2010; Jhamtani, 2011; Liebman and Dyck, 1993; Snapp et al., 2010; Tilman et al., 2002; Woodfine, 2009). 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 service 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 analyze adoption of a combination of these SAPs and their impacts on income and agrochemical use. Specifically, the paper focuses on two objectives. First, we analyze 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 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 an 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 (Khanna, 2001; Wu and Babock, 1998). 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 1644 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 SAP packages. Of the 1644 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 2 shows the interdependence of SAP 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 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

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

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