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Analysis

A bio-economic analysis of the benefits of conservation agriculture: The case of smallholder farmers in Adami Tulu district, Ethiopia

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ABSTRACT

This study analyses the potential impact of conservation agriculture (CA) and its binding constraints for adoption in smallholder farming systems in a drought-prone district of central Ethiopia. We develop a dynamic household bio-economic model by taking into account the existing farming system, resource constraints and market imperfections. Climate-induced production risk is introduced into the model by estimating a weather-specific production function using data generated from a crop simulation model. It is found that the full package of CA, which consists of minimum tillage, mulching and crop diversification, does not appear to be in the best interest of smallholder farmers. However, loosely defined CA practises such as sole maize production with conservation tillage and maize–bean intercropping with conventional tillage, which are not currently practised in the study area, are likely to be adopted by the farmers. The results further demonstrate that time preference, risk aversion, limited credit and market access are key constraints to CA uptake. However, merely addressing these constraints may be insufficient incentives for smallholder farmers to fully adopt CA practises. It is important to identify conditions under which the full package CA can be effectively adopted before it is widely promoted.

1. Introduction

Smallholder agriculture holds a key place in poverty reduction and sustainable development in sub-Saharan Africa (SSA). However, its development is constrained by, inter alia, deteriorating land productivity, dwindling per capita land holdings, market imperfections, and climate variability and change. It is therefore of paramount importance to find sustainable intensification pathways that could increase agricultural productivity while addressing market and climate risks. Towards this end, conservation agriculture (CA) has been widely advocated by international organizations such as the Food and Agriculture Organization (FAO). Biophysical studies indicate that CA improves long-term crop productivity, yield stability, and ecosystem services, while reducing human and animal labour (Hobbs, 2007; Kassam et al., 2009).

CA has been promoted as a package that consists of minimum tillage, mulching and crop diversification and has been widely adopted in the United States of America and Australia. However, CA's adoption pathway does not appear to be smooth in developing countries, particularly in SSA. Although smallholder farmers in the region have been practising aspects of CA for some time, there appears to be some reluctance in taking it up fully. Despite the aforementioned benefits of CA, there are concerns about whether these benefits can be realized across heterogeneous biophysical conditions. In the short-term, CA could also lead to a fall in crop yield (Giller et al., 2009). This implies that it involves inter-temporal trade-offs. On the other hand, studies show that subsistence farmers tend to have high discount rates and short planning horizons, given credit market imperfections in developing countries (Holden et al., 1998).

A smallholder farmer's investment in CA also involves trade-offs with other livelihood activities. Maintaining a certain level of crop residue such as mulch is one of the anchors of CA. This aspect of CA could be questioned in mixed crop-livestock production, which is a salient feature of many farming systems in SSA (Valbuena et al., 2009). Livestock is increasingly becoming dependent on crop residue for feed due to reduced fallow and grazing land (Benin et al., 2003). This means that farmers are confronted with the choice of investing in crop residues as mulch for increasing crop productivity as opposed to feed for livestock production. The decision hinges on the relative return to investing in crop residues in the two alternative ventures. Thus, the success of CA is essentially associated with the economic importance of livestock in the farming system.

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Crop diversification is also one of the pillars of CA, which involves integrating legumes into cereal farming systems such as maize. This implies that farmers need to reduce maize production in order to free a portion of their farm land for legume production. Market imperfections compounded with high transaction costs could lead farmers to be subsistence oriented (Barrett, 2008). Consequently, minimizing maize production, which is an important staple crop in the majority of SSA countries, might not appear worthwhile to subsistence farmers. Moreover, it might be difficult to integrate legumes, which has a lower amount of crop biomass, into a mixed crop-livestock production farming systems as it might fail to provide sufficient feed for livestock. The other facet of CA is zero or minimum tillage. One of the purposes of tillage is to remove weeds and hence reducing tillage might mean an increased incidence of weed infestation (Giller et al., 2009). This could increase labour demand or herbicide cost for weed clearance. Thus, the level of acceptance of this component by farmers depends on the labour and financial endowments of a farm household given imperfections in the labour and credit markets.

Studies on CA tend to revolve around the biophysical benefits without due consideration for the decision maker — the household. To gain insight about the underlying reasons for the low adoption of CA in SSA, it is worthwhile to extend plot level analysis to the farm household level. There have been limited econometric studies on CA and the focus of such studies has often been on the identification of characteristics that differentiate adopters from non-adopters (e.g., see Knowler and Bradshaw, 2007). There are also concerns that even the existing low adoption rates could not have been achieved without additional incentives from donor-driven projects (Giller et al., 2009). This raises questions about the usefulness of econometric adoption studies, which are conducted without evaluating the profitability of these technologies per se. Also, smallholder farmers in rain-fed agriculture exhibit risk averse behaviour due to thin credit and insurance markets (Christiaensen and Dercon, 2011). It is thus important to investigate the implications of adopting CA for production risk. The paucity of empirical economic studies on CA can be partly attributed to lack of observed data as some of the components have not yet been adopted. In order to get around this difficulty, the present study develops a dynamic household model to ex ante assess the likelihood of adoption of CA, and to assess the impacts on household welfare and land productivity. We also examine whether sequential adoption could lead to full-scale adoption of CA. Additionally, the study attempts to uncover the binding constraints for its adoption and it proposes policy options for increasing its adoption. A dynamic household model is well-suited to examine the trade-offs involved across the different activities undertaken by farmers, including the inter-temporal trade-offs.

Previous studies have also developed dynamic household models in smallholder agriculture settings with the view to assess the potential impact of technologies and their likelihood of adoption, as well as the efficacy of different policy options for sustainable intensification. The focus of these studies have been on soil and water conservation technologies (e.g., stone and soil bunds, and *Fanja-juu*), tree planting, non-farm income, food for work, population pressure and drought (e.g., see Shiferaw and Holden, 1999; Holden et al., 2004a; Holden and Shiferaw, 2004; Holden et al., 2004b; Holden et al., 2006). However, these studies have not investigated emerging sustainable intensification options such as conservation agriculture. Also, they have ignored the wide-range of climate scenarios to which agricultural technologies could be exposed. To address these deficiencies, this study estimates yield response functions based on data generated from a crop simulation model using 30 years of weather data. Climate-induced production risk, which is a crucial factor in smallholder farming, is accounted for in the model. The use of simulated data in the model also offers the extra advantage of estimating continuous yield response functions, whereas many applied bio-economic models tend to rely on discrete input–output relationships due to lack of sufficient data (Ruben and van Ruijven, 2001).

The remainder of the paper is organized as follows. The next section sets out the conceptual and analytical frameworks of the study. This is followed by a description of the study area and data. Section 4 presents and discusses the results of the crop simulation and bio-economic models. Section 5 contains the summary and conclusion, as well as suggestions for future research. A detailed description of the model is provided in Appendix A.

2. Methodology

2.1. Conceptual Framework

Smallholder farmer resource allocation decisions could be better understood in the context of the theory of the household farm. A peasant household is both a producing and consuming unit. According to standard neoclassical economic theory, there is a competitive market for both inputs and outputs and farm households allocate their resources in a way that maximizes their profit. The profit generated then becomes a budget constraint in a consumption decision and serves as the only bridge between production and consumption. This approach implies that production and consumption decisions are taken sequentially (Taylor and Adelman, 2003).

However, neoclassical economic theory fails to adequately explain the actual behaviour of smallholder farmers in a developing country context. There is strong evidence of market imperfections in both input and output markets in developing countries due to transaction costs and information asymmetry (DeJanvry, 1991). The Ethiopian agricultural market is not an exception to this (Osborne, 2005). When markets constrain smallholders either from selling their produce or buying commodities of their choice, they engage in subsistence production rather than producing according to their comparative advantage. If the labour market is missing or imperfect, the household's demand for leisure will have an impact on the amount of labour to be utilized for production. In such cases resource endowment also affects production decisions. For instance, a household with a limited labour pool responds differently from a labour-rich household in adopting a labour-intensive technology. Thus, market imperfection makes production and consumption decisions non-separable (Singh et al., 1986). This implies that consumption and production decisions are interdependent. In this case not only does consumption depend on production but also production relies on consumption. The non-separable household model differs from the separable one in that, in the case of the former, the profit maximization objective has one more constraint-market imperfection, which may cause efficiency loss (Mendola, 2007).

However, the non-separable model also does not fully reflect the actual behaviour of peasant households. For example, it ignores the risk and uncertainty associated with agricultural production, which affects the behaviour of farm households (Mendola, 2007). Agriculture is a risky business as it is subject to climate variability, market and policy uncertainty (Ellis, 1993). For example, a farmer needs to decide whether to purchase inorganic fertilizer or not before the season unfolds. There are two scenarios; if the season happens to be conducive for crop production, applying inorganic fertilizer benefits the farmer. But if the season turns out to be unfavourable, application of fertilizer leads to financial loss. The choice is contingent on the attitude of the farmer towards risk. In the absence of credit markets and effective risk-management instruments such as price stabilization and futures markets, poor smallholder farmers manifest risk averse behaviour (Dillon and Anderson, 1971; Binswanger, 1980).

Expected utility is a standard theory to describe decision making under uncertainty. It is based on the independence and continuity assumption. Despite its theoretical elegance, doubts regarding its capability to mimic observed behaviour have been raised. In response to this, Roy (1952) introduced the safety first approach, where agents are