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Research Paper

Ex-ante welfare impacts of adopting maize-soybean rotation in eastern Zambia

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ABSTRACT

This paper estimates the welfare impacts of adoption of maize-soybean rotation in eastern Zambia using data from on-farm trials and household survey data collected from over 800 households. The on-farm trials were conducted from 2012 to 2015 while the household survey was conducted in 2012. The study evaluated maize-soybean rotation where soybean was grown with and without inoculants and inorganic fertilizer, whereas continuous maize cropping was used as a control. The paper estimated household level income changes and poverty reduction due to adoption of maize-soybean rotation using market level economic surplus as well as household level analyses to allocate economic surplus changes to individual households. The results showed that several factors influence the adoption of maize-soybean rotation, including land ownership, education, and age of the household head. Results also showed that adoption of maize-soybean rotation reduced per-unit production costs by between 26 and 32% compared to continuous maize. Ex-ante welfare impact analysis showed significant potential income gains and poverty reduction following adoption of maize-legume rotation in eastern Zambia. The paper concludes with implications for policy to promote wider adoption of soil fertility management practices such as maize-soybean rotation for increased maize productivity in Zambia.

1. Introduction

It is widely recognized that broad-based technological change in agriculture is critical for achieving agricultural productivity growth and poverty reduction in Sub-Saharan Africa. In Zambia, agricultural productivity growth is one of the key policy objectives for achieving sustainable economic growth, poverty reduction, and improved nutrition, health, and social well-being (Kalinda et al., 2014; Sitko et al., 2011). Maize is a staple food in Zambia and is mostly grown by smallholder farmers under low soil fertility, limited use of high yielding varieties and inorganic fertilizers (Langyintuo and Mungoma, 2008; Heisey and Mwangi, 1996). As a result, the average maize yields on farmers' fields remain very low.

Increasing and stabilizing the productivity of maize in inherently poor soils is critical for improving food security. The use of soil fertility enhancing legumes in the maize-based systems holds a considerable promise to not only boost productivity but also to provide nutritional and income benefits for the poor. Cereal-legume rotation which is one of the options for the Integrated Soil Fertility Management (ISFM) (Vanlauwe et al., 2015; Sanginga et al., 2003) has a number of benefits for both farmers and the environment, including soil fertility improvement through nitrogen fixation, reduction of diseases and weed and insect populations, and increases in soil-carbon content, which is essential for increasing yields and mitigating the effects of climate change (Govaerts et al., 2007; Hutchinson et al., 2007; Andersson et al., 2014; Garrison et al., 2014; Pretty, 2008; Thierfelder and Wall, 2010). Past research on maize-soybean rotation has shown that under farm conditions maize grown after soybean yields about 1.5 tons/ha, more than the farms with continuous maize (0.5 tons/ha) in Zimbabwe (Kasasa et al., 1999). Other studies in West Africa showed that, on average, maize yields following legumes were higher than that of continuous maize cultivation by between 20 and 38% (Sanginga, 2003; Yusuf et al., 2009).

A number of studies have assessed the ex-post (e.g. Abdulai and Huffman, 2014; Becerril and Abdulai, 2010; Kassie et al., 2011; Shiferaw et al., 2014) as well as the ex-ante (e.g. Akinola et al., 2009; Kostandini et al., 2013, 2016; Alene et al., 2009, 2013) impacts of agricultural technology adoption in Africa. Most of the past ex-ante studies have used the economic surplus model to estimate the aggregate benefits arising from adoption of yield increasing technologies (e.g.

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Akinola et al., 2009) but do not go beyond market level economic surplus to allocate these benefits to individual households. This paper applies a procedure to allocate market-level economic surplus changes to individual households to estimate household level income changes and poverty reduction associated with adoption of maize-soybean rotation in eastern Zambia. To our knowledge, this is the first study to attempt to allocate benefits from an experimental setting to individual households in Zambia. The paper contributes to the growing literature on impacts of technology adoption by estimating the potential impacts of adopting maize-soybean rotation in Zambia. Specifically, we estimate the benefits of maize-soybean research using economic surplus analysis and allocate this surplus to individual households. To achieve this, we combine data from on-farm trials with rich household level data. This ex-ante approach can therefore be a valuable tool for impact evaluation and research priority setting.

The rest of the paper is organized as follows. Section 2 provides an overview of the methodology used in the study. The data description and descriptive statistics are given in Section 3, whereas 4 presents the empirical results and discussion. The last section draws conclusions and policy recommendations.

2. Methodology for ex-ante assessment

2.1. The economic surplus method

To evaluate the benefits of maize-soybean rotation, we draw on the approaches by Alston et al. (1995), Alwang and Siegel (2003) and Moyo et al. (2007). Following Moyo et al. (2007), aggregate economic surplus analysis is combined with household-level data analysis to construct ex-ante estimates of changes in poverty resulting from adoption of maize-soybean rotation. While the surplus analysis provides estimates of changes in economic surplus, the household-level analysis provides estimates of household-specific changes in income by allocating economic surplus changes to individual producers and consumers. The household income changes can then be used to estimate changes in aggregate income and poverty.

The economic surplus method is the most widely used procedure for economic evaluation of benefits and costs of a technological change (Alene et al., 2013). According to Alston et al. (1995), the first step in calculating the benefits is the estimation of the unit cost reduction (*K*-shift) resulting from the new technology. The *K* can either be estimated using information provided by scientists associated with the new technology or calculated from on-farm trials.[1] Second, information on the expected adoption rates, as well as their evolution over time is gathered. Third, information on the market associated supply and demand elasticities and equilibrium prices and quantities is combined with the first two steps. Using these steps, one can estimate the price, quantity and corresponding economic surplus changes associated with technology adoption (Moyo et al., 2007). The difficulty is to allocate these surplus changes to individual households.

Economic surplus changes are usually calculated under various market scenarios, with the most common being either under open or closed market situations. In this study, we adopt the open market situation. The small country assumption is often suitable because most of the agricultural products are tradable and most regions or countries do not influence international prices significantly (Alston et al., 1995). In a small open economy, the country does not affect the world price, hence the economic surplus change is equal to the producer surplus, which implies that the primary beneficiaries from adopting maize-soybean rotation are the maize producers either through sales or consumption at home (Fig. 1). In Fig. 1, *D* represents the demand curve, consumption *C*, and production Q_0, defines the initial equilibrium at the world market price, *Pw* (which is a constant and defines the opportunity cost of resources used in production and consumption), with a traded quantity, QE_0 (representing exports), equal to the size of the difference between consumption and production. Maize-soybean rotation research leads to a shift in the supply curve *So* to S_1 and production increases to Q_1. This action results in an increase in maize exports to QE_1 and since Zambia does not affect the world price of maize, the economic surplus is equal to the change in producer surplus (area J_0abJ_1). The surplus change captures the entire short run benefits of adoption, assuming prices in all other markets are not affected by the supply shift (Moyo et al., 2007).

In the graph, the unit cost reduction (*K*) due to the adoption of the new technology is represented by:

$$K = \frac{\Delta P}{P_w} = \frac{a - e}{P_w} \tag{1}$$

where ΔP depicts the price change and *Pw* is as defined above.

2.2. Welfare effects: allocating surplus to households

In allocating the surplus to households, three steps are involved (Moyo et al., 2007). First, we calculate the total household expenditure[2] per capita (which we use as a proxy for income) using household level data and compare it to the poverty line. Note that household expenditure includes both expenditure on food and non-food items (e.g. expenses on health, education, housing and clothing); second we use the propensity scores to determine which households are most likely to adopt maize-soybean rotation and estimate the household welfare changes and; third we establish the change in the number of poor households resulting from adoption. The most commonly used indices to estimate poverty are the Foster Greer Thorbeck (FGT) indices defined as:

$$P_\alpha = \frac{1}{N}\sum_{i=1}^{q}\left[\frac{z - y_i}{z}\right]^\alpha \tag{2}$$

Where N is the total number of people, q is the number of poor people, y_i is the household income per capita, z is the poverty line and α is a parameter of inequality aversion. It follows that when $\alpha = 0$, the formula reduces to the headcount ratio which shows the proportion of the population that lives below the poverty line. When $\alpha = 1$, P_α is the poverty gap ratio, which measures the depth of poverty and when $\alpha = 2, P_\alpha$ measure the severity of poverty and reflects the degree of inequality among the poor. The FGT class of poverty measures satisfies a convenient decomposability property (Ray, 1998). In our case, the FGT indices are appropriate because they allow us to assess poverty across adopters and non-adopters.

Maize production and household incomes change due to adoption of the maize-legume rotation is related to the value of agricultural production and the per unit cost reduction that results from adoption such that the change in household income in a small open economy for the *i*th household is:

$$d\pi_i \approx K_iP_iQ_i(1 + 0.5K_i\varepsilon) = J_0abJ_1 \tag{3}$$

P_i is the pre-research price, Q_i is the pre-research quantity, ε is the elasticity of supply[3] and K_i is the proportionate shift downwards in the marginal cost curve (supply curve) due to research.

2.3. Adoption of maize-legume rotation at household level

In order to estimate ex-ante changes in poverty, it is important that farmers who are likely to adopt modern agricultural technologies are

[1] We use this method in estimating the *K*-shift.

[2] In the subsequent sections, we use the term "household income" to mean "household expenditure".

[3] Previous studies (e.g. Katepa, 1984; Nakaponda, 1992; Harber, 1992) estimated supply elasticities for maize ranging between 0.21 and 0.8 in Zambia. In this study, we use an average of 0.51 as the elasticity of supply.