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Push–pull farming system in Kenya: Implications for economic and social welfare

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ABSTRACT

This study examines the farm-level economic benefits and aggregate welfare impacts of adopting push–pull technology (PPT)—an innovative, integrated pest and soil-fertility management strategy—with a set of household- and plot-level data collected in western Kenya. The evaluation is based on a combination of econometric and economic surplus analysis. Treatment effect estimates are used to assess the technology-induced shift in the maize supply curve, which is then used as an input to the economic surplus analysis. Finally, the aggregate poverty impact is computed using the economic surplus estimates. We observe that the adoption of PPT led to significant increases in maize yield and net maize income. The technology has significant potential benefit in terms of increasing economic surplus and reducing the number of people considered poor in western Kenya. Important factors influencing the decision to adopt PPT included access to information, household education, social capital, and social networks. We conclude that effective policies and development programmes for promoting PPT in Kenya should include information delivery and education mechanisms that are more effective.

1. Introduction

In this paper, we assess the factors that influence the adoption of push–pull technology (PPT) in western Kenya, and the effects of such adoption on farm-level outcomes and potential aggregate economic and poverty reduction benefits in the research area. PPT is an organic agricultural technology that does not rely on the increased use of chemical inputs, such as pesticides or nitrogen fertiliser. The effect of PPT adoption is critical topic because it could potentially allow farmers to increase their maize productivity and incomes without increasing their impact on the surrounding environment or their reliance on frequently unreliable agricultural input markets. Moreover, studies on the adoption of agricultural technology and its farm-level impacts are relatively common, but empirical studies on the aggregate welfare effects of adoption of such technologies (e.g. by integrating economic surplus analysis with econometrics, as we do here) are scant.

Improving food security and reducing poverty are policy priorities in sub-Saharan Africa (SSA) and have been the focal point of policies on agriculture and rural development in the region. Increasing agricultural productivity is widely recognised as a major pathway to reducing food insecurity and poverty in SSA (AGRA, 2014; Christiaensen and Demery, 2007; Gollin, 2010; Kijima et al., 2008; Owens et al., 2003; Thirtle et al., 2003). The literature on SSA (Diao et al., 2010; Minten and Barrett, 2008) suggests that growth in staple crop productivity has a greater potential to reduce poverty than any other development in the agricultural or non-agricultural sectors. However, agricultural productivity in SSA countries is still inadequate to address poverty, achieve food security, and lead to sustained economic growth (Dessy et al., 2006; Pretty et al., 2011; World Bank, 2008).

The current situation also reveals that a large gap still exists between actual and potential farm yields for major staple crops in SSA (Van Ittersum et al., 2016). For instance, between 2003 and 2012, actual yields of rain-fed maize—the dominant staple and cash crop in SSA—ranged from 1.2 t/ha to 2.2 t/ha, which represents only 15%–27% of the yield potential (Van Ittersum et al., 2016). The major constraints to increasing productivity and, hence, closing yield gaps, include socioeconomic and institutional hurdles to access farm input; poor soil fertility linked to soil erosion and nutrient depletion; poor management of pests (i.e. insects, diseases, weeds); and, more recently, climate change and variability (AGRA, 2014; De Groote et al., 2008, 2010; Gibbon et al., 2007; Kfir et al., 2002; Khan et al., 2014; Kijima et al., 2012; Minten et al., 2013; Reynolds et al., 2015; Tadele, 2017). This phenomenon is illustrated by the fact that

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low soil fertility, low soil nitrogen, and drought have been shown to reduce maize yields in Africa by 62%, 76%, and 54%, respectively (Gibbon et al., 2007). Another example is stemborer insects, which cause cereal grain yield losses ranging from 10% to 88% (Kfir et al., 2002) and the parasitic *Striga* weed (witchweed) destroying entire harvests (Kanampiu et al., 2002). To overcome these challenges and close yield gaps, farmers require multifunctional interventions that are feasible, economically sustainable, and effective.

Researchers from the International Centre of Insect Physiology and Ecology (ICIPE) in Kenya and Rothamsted Research in the United Kingdom developed PPT to improve the long-term sustainability of the agricultural system by reducing cereal crop pests such as stemborer insects and *Striga* weed while increasing soil fertility and fodder production in quality and quantity. In the PPT system, cereals such as maize are intercropped with perennial fodder legumes (*Desmodium)* that repel ('push') stemborers and suppress *Striga*. The cereal crops are also surrounded by a border of perennial fodder grass (e.g. *Pennisetum purpureum*/Napier grass or *Brachiaria* species) that attracts ('pulls') stemborers away from cereal plants (Khan et al., 2014; Pickett et al., 2014). The technology provides additional benefits such as enhancing soil fertility through nitrogen fixation and the addition of organic matter, practically eliminating soil erosion, suppressing weeds, and providing high-quality livestock forage that increases animal health and milk production, which contributes to improved incomes and nutritional security in smallholder households. The PPT approach can also, at least potentially, enhance human health and increase biodiversity through reducing the use of costly synthetic insecticides and herbicides that are unaffordable by most smallholder farmers (Pickett et al., 2014).

Despite PPT's enormous potential benefits, its adoption is limited and little is understood about its economic and welfare benefits. Understanding the PPT adoption process and its impact are relevant to design strategies that can facilitate its wider adoption. Notably, the literature on PPT mainly focuses on its efficacy (Khan et al., 2008a), how effective its dissemination pathways are (Amudavi et al., 2009; Murage et al., 2012), and its profitability (De Groote et al., 2010; Fischler, 2010; Khan et al., 2008b; Murage et al., 2015a, 2015b).

This paper contributes to the existing adoption and impact literature through systematically exploring the farm-level economic benefits and aggregate welfare impacts of PPT adoption. Specifically, this paper has three objectives: 1) assess the determinants of PPT adoption, 2) assess farm-level impacts of adoption of PPT (i.e. maize yield, cost of maize production, and net maize income), and 3) assess the ex-ante aggregate welfare effects (i.e. change in total economic surplus and poverty) of adoption of PPT in western Kenya. An ex-ante impact study was conducted because PPT is not sufficiently widespread to conduct an ex-post aggregate welfare or market-level impacts analysis.

The ex-ante analysis is based on a combination of econometric and economic surplus methods. We use econometric methods to compute the PPT-induced shift in maize supply by estimating the changes in maize yield and cost of production due to the introduction of PPT while controlling for selection biases that stem from differences in the observed and unobserved characteristics of adopters and non-adopters. In the first step, the changes in maize yield and cost of production are estimated using a cross-sectional fixed effects estimator. The second step involves plugging changes in yield and cost of maize production into an economic surplus model to compute potential economic surplus gains. Finally, the estimated economic surplus is used to compute the potential impact of adoption on aggregate poverty.

Moyo et al. (2007) and Manda et al. (2017) estimate the ex-ante economic surplus effects of the adoption of improved groundnut varieties and maize–soybean rotation practice, respectively, and use the economic surplus estimates to evaluate the ex-ante poverty impacts of the adoption of groundnut varieties and maize–soybean rotation. Ex-post impact studies in the literature link economic surplus analysis with poverty analysis and include Alene et al. (2009), Zeng et al. (2015), and Kassie et al. (2018).

In this paper, the approach employed by Alene et al. (2009) to evaluate the impact of improved maize varieties on economic surplus and poverty is used. However, instead of using econometrics to estimate the shift in supply, Alene et al. (2009) rely on a combination of on-farm variety evaluation trials, adoption surveys, and expert estimates. Zeng et al. (2015), by contrast, use a cross-sectional econometric approach to estimate the supply shift in their attempt to determine the impact of improved maize varieties on the total change in economic surplus and poverty in Ethiopia. Kassie et al. (2018) extend the approach for panel data and adoption of multiple technologies—to calculate the cost reduction per unit of output and evaluate the impact of combinations of maize production technologies and practices (i.e. maize varieties, chemical fertilisers, and cropping diversification) on the total change in economic surplus and poverty. The study we report on in this paper employs the same methods as those in Kassie et al. (2018).

2. Methodology

2.1. Estimation strategy

When using observational data to estimate the causal effect of technology adoption on farm-and market-level outcome variables, an important econometric challenge is to cater to selection bias causes by the observable and unobservable attributes that simultaneously affect household adoption decisions and outcomes of interest. Technology adopters may be systematically different from the non-adopters with respect to characteristics that are observed (e.g. resource endowments, proximity to input and output markets, access to extension, education, training, land quality) and unobserved (e.g. motivation, risk preference, managerial ability), resulting in inconsistent estimates of the effect of agricultural technology adoption on outcomes of interest. For example, the most motivated farmers with greater managerial abilities are assumed to be more likely to (i) adopt improved agricultural technologies such as PPT and (ii) engage in other yield-augmenting farm management practices. If the assumption of such a systematic difference between adopters and non-adopters is correct, the estimated effect of adoption would be biased upwards due to a positive correlation with unobserved management skills.

In this study, three measures were taken to overcome the potential selection bias. The first measure was to include several explanatory variables that influenced PPT adoption and outcomes of interest. Secondly, the data allowed for the use of household and county fixed effects to capture household and county-specific unobserved heterogeneities. The data derived from two growing seasons and repeated plot observations per household had a panel structure that enabled the use of a household cross-sectional fixed effects estimator to control for unobserved characteristics.[1] Studies that use plot-level information to construct panel data and control for farm-specific effects include Kassie and Holden (2007) and Udry (1996). The county-specific characteristics could include weather influences as well as differences in development services (e.g. access to extension, credit, markets) and the policy environment, which can influence PPT adoption and farmers' performance.

As a third measure, we used the endogenous switching regression (ESR) framework—a variant of the instrumental variables approach—to instrument the adoption decision (Abdulai and Huffman, 2014; Carter and Milon, 2005; Di Falco et al., 2011; Kassie et al., 2015a, 2017; Shiferaw et al., 2014; Teklewold et al., 2013). In the ESR framework, separate regressions were estimated for the adopters and non-adopters of PPT, respectively. This separation allows us to capture the slope

[1] Of the total usable maize plot observations (2,148), approximately 4% of plots have one observation. We ran fixed effects model including and then excluding these observations and observed no remarkable difference in the results (the results are available from the authors). We therefore included the 4% of households in our final analysis.