Journal of Environmental Management 203 (2017) 106–113

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Research article

Measuring the impacts of adaptation strategies to drought stress: The case of drought tolerant maize varieties

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ARTICLE INFO

Article history:
Received 1 February 2017
Received in revised form
25 June 2017
Accepted 26 June 2017

Keywords:
Downside risk
Drought tolerant maize varieties
Endogenous switching regression
Nigeria
Productivity
Welfare

ABSTRACT

This study measured the impacts of drought tolerant maize varieties (DTMVs) on productivity, welfare, and risk exposure using household and plot-level data from rural Nigeria. The study employed an endogenous switching regression approach to control for both observed and unobserved sources of heterogeneity between adopters and non-adopters. Our results showed that adoption of DTMVs increased maize yields by 13.3% and reduced the level of variance by 53% and downside risk exposure by 81% among adopters. This suggests that adoption had a “win-win” outcome by increasing maize yields and reducing exposure to drought risk. The gains in productivity and risk reduction due to adoption led to a reduction of 12.9% in the incidence of poverty and of 83.8% in the probability of food scarcity among adopters. The paper concluded that adoption of DTMVs was not just a simple coping strategy against drought but also a productivity enhancing and welfare improving strategy. The results point to the need for policies and programs aimed at enhancing adoption as an adaptation strategy to drought stress in Nigeria and beyond.

1. Introduction

Agriculture in Africa is highly vulnerable to climate change and variability (Schlenker and Lobell, 2010; Haile et al., 2017). The occurrence of climate change-induced rainfall shock in general and drought shock in particular affects food security in many developing countries (Wossen et al., 2016). As a result of climate change, droughts have become more severe, longer, and more frequent (Hyman et al., 2008). The economic costs can, therefore, be enormous as drought has the potential to cause a severe food crisis, hunger and malnutrition, as well as sustained long-term poverty traps due to the limited adaptive capacity of smallholders (Collier et al., 2008; Bryan et al., 2013). Of particular interest, at least in the context of Africa, is the adverse effect of drought on the production of maize, Africa's most important food crop. Maize is grown on nearly 30 million ha of land, supporting over 300 million people on the continent (Tambo and Abdoulaye, 2012; La Rovere et al., 2014; Fisher et al., 2015). However, maize is also a crop that is highly susceptible to drought. According to Fisher et al. (2015), around 40% of Africa's maize-growing areas face occasional drought stress, resulting in yield losses of 10–25%. Moreover, Schlenker and Lobell (2010) pointed out that production of maize would decline by 22% in sub-Saharan Africa (SSA) by 2050 due to climate change. Reducing the vulnerability of maize producers to drought shocks is, therefore, an important entry point to improve productivity and hence reduce the prevalence of food insecurity and poverty.

Efforts have been made to develop adaptation strategies against drought stress. Notable among these was the DTMA project - Drought Tolerant Maize for Africa - which was initiated with the aim of developing and deploying drought-tolerant maize varieties (DTMVs). As the project targeted production zones where the rainfall patterns and climatic conditions varied considerably within and among seasons, the varieties that were developed were selected for high yield potential under both drought stress and favourable growing conditions. Over 200 distinct DTMVs were released in 13 countries across SSA with the support of the DTMA project in the last nine years (Fisher et al., 2015). These varieties

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http://dx.doi.org/10.1016/j.jenvman.2017.06.058
0301-4797/

were endowed not only with tolerance to drought but also with high levels of lysine and tryptophan, better nitrogen use-efficiency and resistance to the major foliar diseases (Fisher et al., 2015). Adoption will therefore be crucial as it might reduce the variance and downside risk (probability of crop failure) associated with maize production.

A drought shock, besides exacerbating current levels of food insecurity, may lead to sustained long-term asset poverty traps as poor farmers may sell their key assets, such as land and livestock, as a coping measure. In addition, drought-induced crop failures can adversely affect labour supply to agricultural production, education, and health outcomes. The lack of formal insurance and social safety nets in many African countries implies that the risk of drought can be consequential and that variance and downside risk-reducing technologies can provide substantial gains for poor and food insecure farmers (Kostandini et al., 2013). As such, DTMVs can serve as a risk reducing technology option in the absence of formal insurance and safety net mechanisms (La Rovere et al., 2014; Fisher et al., 2015). In doing so, they will enhance food security while acting as an insurance against crop failure. However, empirical evidence on this insurance function is non-existent.

As production risk is the inherent feature of African agriculture, investigating the risk reducing effects of DTMVs is one of the objectives of this paper. We considered risk exposure in addition to productivity as both the variability and skewness of maize yield affect adoption decisions. In this context, besides their effect on productivity, DTMVs can generate benefits by reducing farmers' exposure to risk in general and downside risk in particular.[1] Since any firm economic understanding of the potential roles of DTMVs under climate change and variability requires an understanding of the dynamics and cross-sectional patterns of adoption, the paper also examined the main determinants of adoption as well as the potential benefits associated with it. The main contributions of this paper are twofold: (1) to investigate how adoption affected productivity as well as exposure to drought risk by explicitly estimating its effect on the variance and skewness of maize yields; and (2) to assess the effects of adoption on household food security and poverty. The rest of the paper is organized as follows. Section 2 presents the conceptual framework. The data and descriptive statistics as well as the empirical estimation strategy are presented in Section 3. The results are presented in Section 4. Section 5 concludes with implications for policy.

2. Conceptual framework

Following Koundouri et al. (2006), we investigated the underlying effects of production risk and the risk-mitigating role of DTMVs within the expected utility framework. In particular, we used the moment-based (Antle, 1983) approach which enables the flexible estimation of a stochastic production function under uncertainty. Consider a typical maize producing farmer with a production function $y = g\,(\mathbf{x}, \boldsymbol{s}, \mathbf{w}, \mathbf{e})$, where $\boldsymbol{y}$ is maize output, $\mathbf{x}$ is a vector of inputs other than DTMVs, $\mathbf{s}$ represents improved seeds (in this case, DTMVs), $\mathbf{w}$ is weather variables, $\boldsymbol{e}$ is a vector of village fixed effects, and g ($\mathbf{x}$, $\boldsymbol{s}$, $\mathbf{w}$, $\mathbf{e}$) represents the corresponding production technology, given $\mathbf{x}$, $\mathbf{s}$, $\mathbf{e}$, and $\mathbf{w}$. We assume that the production function is strictly concave and twice differentiable with the usual conditions $g'(\boldsymbol{x}, \boldsymbol{s}, \boldsymbol{w}, \boldsymbol{e}) > 0$ *and* $g''(\boldsymbol{x}, \boldsymbol{s}, \boldsymbol{w}, \boldsymbol{e}) < 0$. Furthermore, suppose that a typical farmer acquires input $\boldsymbol{x}$ with a unit cost of $\boldsymbol{r}$ and DTMVs with a unit cost of $\boldsymbol{c}$. In our setting, the source of production risk is the weather conditions ($\mathbf{w}$) whose distribution is given by $\boldsymbol{w} \sim \chi(\mathbf{w}|\boldsymbol{\omega})$, where $\boldsymbol{\omega}$ is the micro-climate variables such as drought shock. This distribution is exogenous to the farmer's action. This is the only source of risk we considered; prices $\boldsymbol{p}$ and cost of production $\boldsymbol{c}\&r$ are assumed to be non-random as farmers are price-takers in both input and output markets.

To capture the riskiness of the production process, we followed the approach of Di Falco and Chavas (2006), Antle (1983), and Zhang and Antle (2016). In particular, we captured the risk component of the production function by introducing the variance and skewness of maize yield through the moment-based approach as follows:

$$E\left[g(x,s,e,\ w) - f_1(x,s,e,\ w))^k\right] = f_k(\mathrm{x},\mathrm{s},\mathrm{e},\mathrm{w},\beta_k)\,\forall k \geq 2 \tag{1}$$

where $f_1(\cdot) = E(g(x,s,e,w)$ represents the mean of the production function. Given the above equation, the first moment (mean) of the production function is defined as:

$$E[g(x,s,e,w)] = f_1(x,s,e,w,\beta_1) - cs - rx = \mu_1 \tag{2}$$

Similarly, the second moment (variance) of the production function is defined as:

$$E\left[\left(g(x,s,e,w) - E(g(x,s,e,w))\right)^2\right] = \mu_2 \tag{3}$$

and the third moment (skewness) of the production function is defined as:

$$E\left[\left(g(x,s,e,w) - E(g(x,s,e,w))\right)^3\right] = \mu_3 \tag{4}$$

As shown by Antle (1987), the specification in Eqs. (2)–(4) can be further expressed as a function of all the moments of the production function using the third order Taylor approximation of the expected utility function as:

$$\begin{aligned} E[u(\pi)] &= f_1(x,s,e,w,\beta_1), f_2(x,s,e,w,\beta_2),\ f_3(x,s,e,w,\beta_3) \\ &= (\mu_1,\mu_2,\mu_3). \end{aligned} \tag{5}$$

where π is the net return from production. Since the farmers are risk-averse they maximize the expected utility of net returns from maize production in the following way:

$$E \max_{xs} E[u(\pi)] = u(\mu_1,\mu_2,\mu_3). \tag{6}$$

The optimum condition for the adoption of DTMVs in elasticity form is then given by:

$$\mu_1^* - \frac{cs}{\mu_1} - \frac{1}{2}\left(\frac{u''(\pi)}{u'(\pi)}s_2\right)U_2^* + \frac{1}{6}\left(\frac{u'''(\pi)}{u'(\pi)}s_3\right)\Bigg)U_3^* = 0 \tag{7}$$

where $\mu_j^* = \frac{\partial u_j}{\partial s}$, s_2 is the variance (or second central moment) of (π) and s_3 is the skewness (third central moment) of π (Antle, 1987; Di Falco and Chavas, 2006). From the above optimal condition, $\mu_1^* - \frac{cs}{\mu_1}$ captures the marginal net return of choosing DTMVs (s^*) and the term $\left\{-\frac{1}{2}\left(\frac{u''(\pi)}{u'(\pi)}s_2\right)U_2^* + \frac{1}{6}\left(\frac{u'''(\pi)}{u'(\pi)}s_3\right)\Big)U_3^*\right\}$ depicts the marginal risk premium of adopting DTMVs (Chavas, 2004; Di Falco and Chavas, 2006; Zhang and Antle, 2016). Since DTMVs are risk-reducing, we would expect farmers to choose them, based on the marginal net return $\left(\mu_1^* - \frac{cs}{\mu_1}\right)$ and the marginal risk premium $\left(-\frac{1}{2}\left(\frac{u''(\pi)}{u'(\pi)}s_2\right)U_2^* + \frac{1}{6}\left(\frac{u'''(\pi)}{u'(\pi)}s_3\right)\Big)U_3^*\right)$.

[1] We included skewness of yield since the variance does not distinguish between unexpected bad events and unexpected good ones. By capturing the skewness of maize yield, we can examine the effect of adoption of DTMVs on downside risk (e.g., a decrease in the probability of crop failure).