



AgEcon SEARCH
RESEARCH IN AGRICULTURAL & APPLIED ECONOMICS

The World's Largest Open Access Agricultural & Applied Economics Digital Library

This document is discoverable and free to researchers across the globe due to the work of AgEcon Search.

Help ensure our sustainability.

Give to AgEcon Search

AgEcon Search
<http://ageconsearch.umn.edu>
aesearch@umn.edu

*Papers downloaded from **AgEcon Search** may be used for non-commercial purposes and personal study only. No other use, including posting to another Internet site, is permitted without permission from the copyright owner (not AgEcon Search), or as allowed under the provisions of Fair Use, U.S. Copyright Act, Title 17 U.S.C.*

The Effect of Index Insurance on Returns to Farm Inputs: Exploring Alternatives to Zambia's Fertilizer Subsidy Program

Katie Farrin* and Anthony G. Murray*

Farrin: Food Security and Development Branch, Market and Trades Division, USDA, Economic Research Service, Washington DC 20024 kmfarrin@ers.usda.gov

Murray: Food Security and Development Branch, Market and Trades Division, USDA, Economic Research Service, Washington DC 20024 agmurray@ers.usda.gov

Selected Presentation prepared for presentation at the Agricultural & Applied Economics Association's 2014 AAEA Annual Meeting, Minneapolis, MN, July 27-29, 2014.

Copyright 2014 by Katie Farrin and Anthony G. Murray All rights reserved. Readers may make verbatim copies of this document for non-commercial purposes by any means, provided that this copyright notice appears on all such copies.

The views expressed are those of the authors and do not necessarily represent the views or policies of the U.S. Department of Agriculture.

The Effect of Index Insurance on Returns to Farm Inputs: Exploring Alternatives to Zambia's Fertilizer Subsidy Program

Anthony G. Murray and Katie Farrin¹

Economic Research Service, USDA

Abstract

A significant volume of research has investigated input subsidy programs in Africa, where government expenditures on such programs are non-trivial. This paper uses panel data from a sample of farm households in Zambia to compare how fertilizer use decisions change in the presence of a formal insurance market. If returns to fertilizer improve under an insurance regime, the use of index insurance can be an alternative to or complement of existing input subsidy programs in the country. After estimating the cost of a simple zero-one, actuarially fair index insurance product that is mandatory for farmers who purchase fertilizer, we run simulations to explore the effect of insurance on household investment in fertilizer. Results show that index insurance, by reducing the disposable wealth of households in years where no payouts occur, can dampen demand for fertilizer at the farm level.

Keywords: weather insurance, technology adoption

JEL Codes: D14, G22, Q12

1. Introduction

African smallholders (generally farmers that cultivate fewer than two hectares) are a critical component of global agricultural productivity. Sufficient food supply in the future is not nearly as certain without higher yields from these smallholders (Godfray et al., 2010). However, smallholder productivity in Africa has traditionally lagged behind other regions of the world, and research into methods for improving yields is ongoing (Fuglie and Rada, 2013). One of the critical components of improved productivity includes adoption of technologies often associated with the Green Revolution. These technologies include fertilizer, improved seeds, and pest management, and have drastically increased output in many Asian countries. Additionally, these technologies not only have improved yields, but have also improved the overall welfare of farmers in Asian countries (Evenson and Gollin, 2003).

Various methods have been used to try to improve adoption of agricultural technologies by African smallholders. One of the most common methods used in southern Africa is input subsidies, where the government subsidizes the cost of procuring inputs, such as fertilizer or drought-resistant seed. Across sub-Saharan Africa (SSA), state-run monopolies selling subsidized fertilizer were extremely common during the 1970's and 1980's, but market reforms initiated by the World Bank and International Monetary Fund promoted market entry by privately owned fertilizer companies, as well as reductions in subsidies (Minot and Benson, 2009). More recently, governments have opted to provide vouchers that farmers may purchase at subsidized prices to obtain fertilizer from local, private agribusinesses (Morris et al., 2007). Supporters of this type of subsidy note that this method encourages private business while still providing subsidized inputs to smallholders, though others argue that this type of subsidy is still inefficient (Banful, 2011; Ricker-Gilbert, Jayne, and Chirwa, 2011). Other techniques have also been used in attempts to increase fertilizer use, such as microfinance and better agricultural extension.

¹Katie Farrin is the corresponding author. *E-mail:* kmfarrin@ers.usda.gov; *p:*(202)694-5149; *f:*(202)245-4779; *address:*1400 Independence Ave., SW, Mail Stop 1800, Washington, DC 20250-1800. The views expressed are those of the authors and should not be attributed to the Economic Research Service or USDA.

Weather-based index insurance has been offered as an alternative method for increasing uptake of agricultural technology while preventing many of the problems associated with input subsidies (Miranda and Farrin, 2012). Correctly implemented index-based insurance cannot be affected by the actions of the farmer and therefore avoids moral hazard and adverse selection (Carter, 2012). Additionally, since the insurance is based on natural phenomena, it is cheaper for insurers to provide coverage because details on specific farmer characteristics are not necessary. In Zambia, input subsidies sponsored by the Zambian government have been prevalent, yet little work has looked at index insurance as an alternative to input subsidies. This paper contrasts the effects of simulated index insurance compared to input subsidies using a three-wave panel of Zambian agricultural households.

The rest of the paper is organized as follows: Section 2 provides a discussion of input subsidy programs in Zambia; Section 3 gives a brief overview of the role of index insurance in farm planning at the household level; Section 4 describes the data; Section 5 introduces a theoretical model of fertilizer investment with and without insurance; Section 6 presents a conceptual framework and introduces a hypothetical index insurance contract; Section 7 presents results; and Section 8 concludes.

2. Fertilizer Subsidies in Zambia

A significant volume of research has explored the input subsidy programs in southern African countries such as Zambia and Malawi. Government expenditures on these programs are non-trivial – \$1 billion annually for 10 African countries (Jayne and Rashid, 2013). In Zambia, input subsidies account for an average of almost 40 percent of the agricultural sector budget, although improvements in agricultural productivity are limited (Mason and Jayne, 2013). Input subsidy programs are designed to increase total fertilizer use for smallholder farmers (Ricker-Gilbert, Jayne, and Chirwa, 2011). The methodology to provide these subsidies has changed over time. Originally, a monolithic government entity administered the input subsidies and singularly provided farmers subsidized fertilizer and improved seed within Zambia in the 1970's and 1980's. The economic costs associated with these programs proved unsustainable, and international organizations forced the government to open the market to private distributors in order to continue receiving assistance (Smale and Birol, 2013). Empirical findings also suggest that subsidies failed to significantly improve yields, with only limited success in increasing fertilizer usage (Morris et al., 2007). An assortment of problems including late delivery of fertilizer, incorrect types of fertilizer, and political manipulation plagued the design of the program (Banful, 2011).

After nearly a decade of stagnant fertilizer use and growing concerns about national food security, several SSA countries, including Zambia, returned to the idea of input subsidies (Banful, 2011). In the late 1990's, Zambia set up an ad hoc Fertilizer Credit Program that lasted until 2002; the program deferred the majority of farmer input costs until after the harvest. Farmers paid market price for fertilizer with an initial down payment of 10 percent, with the remaining 90 percent paid at harvest (Mason, Jayne, and Mofya-Mukuka, 2013). Although this was not a true subsidy, default and failed repayment rates were relatively high, which meant farmers received fertilizer at prices well below market price (Mason and Jayne, 2013). Subsequently, along with other governments in SSA, Zambia introduced "smart" subsidies that attempted to improve private distribution networks, foster relations between rural farmers and agribusinesses, and promote further adoption of improved seed and fertilizer (Minot and Benson, 2009). In Zambia, this program has changed names though the mission remains the same: provide subsidized fertilizer and improved seed to smallholders. Initially called the Fertilizer Support Programme (FSP), input subsidies provided farmers fertilizer and improved seed at roughly half the market price. In later years, the program became the Farmer Input Support Programme (FISP) and minor differences in the program included broader eligibility and a reduction in subsidized inputs to enable access to more farmers (Ricker-Gilbert et al., 2013). An additional input subsidy program, the Food Security Pack Programme, operated as a grant, though its budget is relatively small relative to the larger input subsidy programs described. For an extremely detailed account of these programs, *see* Mason, Jayne, and Mofya-Mukuka (2013).

Eligibility for each of the input subsidies varies slightly but several themes are constant. First, only small farmers are considered eligible; the maximum cultivated land allowed for subsidy program participation is approximately five hectares. Second, out of their land holdings, farmers have to be able to dedicate some of it to maize production (1 hectare under FSP and 0.5 hectares under FISP). Third, farmers have to be members of a farmer cooperative or other participating group and have sufficient resources to be able to pay their share of the fertilizer cost. Finally, if the farmer has previously defaulted on other agricultural credit programs, he is ineligible for the input subsidies. For the

Food Security Pack, eligibility targets females and youth who are otherwise unemployed and cultivate fewer than one hectare of land.

The overall effectiveness of the input subsidy program hinges on its ability to target households that would not have otherwise purchased fertilizer. If households would have purchased fertilizer without the subsidy, then the expected increase in fertilizer is not as large. Evidence from research casts doubt that input subsidy policies are working efficiently (Xu et al., 2009a; Ricker-Gilbert, Jayne, and Chirwa, 2011; Mason and Jayne, 2013). Specifically, these papers highlight the fact that input subsidies “crowd-out” private fertilizer purchases that would have been bought at market prices through private channels had there not been a subsidy (Xu et al., 2009a; Mason and Jayne, 2013). Additionally, not all subsidized fertilizer reaches farmers at subsidized prices. A significant portion of the fertilizer “leaks” onto the open market and is sold to farmers at or near market prices, which further reduces the effectiveness of the program (Jayne et al., 2013). In turn, this means that for every one kilogram of government subsidized fertilizer, total fertilizer use only increases by an additional 0.54 kilograms, nearly halving the expected return (Mason and Jayne, 2013). Additionally, an additional kilogram of subsidized fertilizer only increases maize output by an additional 1.88 kilograms, a relatively small increase (Mason, Jayne, and Mofya-Mukuka, 2013). In Malawi, for example, increases in fertilizer vary depending upon total application, but estimates range between 6.9 and 9.5 kilograms per hectare (Benson, 1999).

In light of the apparent shortcomings of the fertilizer subsidy program in Zambia, we propose index insurance as an alternative approach to increasing smallholder fertilizer use. Farmers can purchase index insurance to help mitigate the risk associated with investment in inputs such as fertilizer, which may only be profitable under favorable weather conditions. A well-designed index insurance contract can protect a farmer against yield losses due to catastrophic weather events; such protection against downside risk may increase the marginal returns to inputs and thus spur investment in fertilizer.

3. Index Insurance

Index insurance products pay out when the realized value of an underlying index either exceeds (e.g., in the case of flood insurance) or falls below (e.g., for drought insurance) a given threshold. The index must be exogenous to the policyholder but should also be significantly correlated with the policyholder’s actual losses (Barnett, Barrett, and Skees, 2008). That a policyholder cannot affect the realization of the index is the feature of index-based contracts that does away with moral hazard; because actual losses are not indemnified, households are incentivized to minimize farm losses – even when they are weather-related.

In addition, index-based products are unique in that, unlike traditional agricultural insurance, all buyers of a particular policy in a given year face the same degree of risk. As the payouts are completely determined by an independent index – not by actual farm outcomes, which may be influenced by an individual’s risk behavior or skill in agricultural management – insurers do not face the same problems with adverse selection that plague policies whose indemnities are based off of actual losses. These characteristics of index insurance contracts lower the risk load on charged premiums, as well as reduce monitoring costs to the insurer. Transactions costs associated with claims verification are also eliminated, which can further reduce premiums faced by farm households.

Given its cost-saving and information asymmetry-reducing advantages, index insurance has been proposed as a risk management tool in developing countries, especially where a large proportion of households rely on agriculture as a livelihood. The availability of formal insurance may induce poor, rural households to make productive investments they would not have made had they only had access to informal risk-coping mechanisms. Uninsured risk at least partially accounts for deficiencies in technology uptake among low-income households. Rosenzweig and Binswanger (1993), using ICRISAT Indian village panel data, reject the hypothesis that agricultural investment composition reflects technical-scale economies, and find support for the hypothesis that asset portfolio choice is highly influenced by farmers risk aversion and wealth, and by the variability of the weather they face. More importantly, the trade-off between profit variability and average returns is large, and the loss of efficiency associated with risk-coping strategies is higher among low-income households; the existence of uninsured weather risk thus results in increased income inequality.

Uninsured risk – especially in SSA – can contribute to low demand for productive inputs. In areas where rainfed agriculture is the norm, highly variable rainfall, in combination with a missing formal risk market, can make fertilizer

unprofitable for farmers (Marinho, 2004). In Ethiopia, for example, farmers are found to place heavy importance on the weather when weighing both current productivity and future investments (Alem et al., 2010). Thus, the introduction of a weather insurance market – which would mitigate the effects of variable rainfall on production income – might induce small farmers to increase their productive investments in inputs, including fertilizer.

There has been little research on how index insurance might be a complement to or substitute for input subsidies, including the fertilizer subsidies employed in Zambia. Results of a randomized controlled trial offering interlinked index insurance-credit contracts to smallholders in Ethiopia show that farmers who *already* display high fertilizer use are more likely to adopt insurance. This indicates that that insurance availability might not increase fertilizer uptake or application rates, but instead might protect existing investments in inputs (McIntosh, Sarris, and Papadopoulos, 2013).² Using framed choice experiments, Marenya, Smith, and Nkonya (2014) find that Malawian farmers heavily prefer fertilizer subsidies to index insurance contracts – even when such contracts are ideal (i.e., they carry zero basis risk) and when premiums are subsidized. However, in this study, the authors assume zero fertilizer use with insurance uptake when they present the various income distributions that result from alternative farm management choices. This paper, in contrast, models index insurance as a net change to disposable income, which can affect farmers' choices regarding input purchase.

4. Data

The Zambian Central Statistical Office, in conjunction with the Ministry of Agriculture and Cooperatives and the Food Security Research Project, established a three-wave, nationally representative panel of agricultural households within Zambia. The survey focuses on agricultural production and household characteristics, with limited information about expenditures and consumption. The initial round of surveys covers the 1999/2000 agricultural season that combines information from an initial survey of respondents in August and September of 2000 with a supplemental survey conducted in May 2001. Another supplemental survey interviewed the same panel households in May 2004 to gain information about the 2002/2003 agricultural season. Finally, a third supplemental survey interviewed households in June and July 2008 to collect the necessary information about the 2006/2007 agricultural season.

A three-stage sample method chose an initial sample of 7,699 households from 70 districts within Zambia (Megill, 2005). Sample attrition occurred throughout the three waves, beginning with the first supplemental survey; only 6,922 households of the initial 7,699 households were re-interviewed. The supplemental survey in 2004 lost an additional 1,564 households (22.6 percent), resulting in 5,358 successful interviews. Only 4,286 households of those that were successfully interviewed in 2004 were re-interviewed in 2008. While there is relatively large attrition loss in the survey, previous research has not found attrition bias within the sample (Mason and Jayne, 2013). Therefore, we use households interviewed in all three waves that report growing maize during at least one agricultural season. The number of households that grow maize increases over the three panel waves. Initially, only 3,150 households report growing maize in 2001. In 3,355 and 3,441 households report growing maize in 2004 and 2008, respectively. Summary statistics for each year of the panel are included in Table 1.

Fertilizer use per hectare increased from the initial panel survey to the last. Average fertilizer use still lagged behind the recommended 200 kilograms per hectare in each year, with the highest rate of fertilizer being applied in the 2006/2007 agricultural season. The number of farmers that use fertilizer increased during each panel wave, with almost 37 percent of the sample using fertilizer by the final wave. The average hectares of maize planted did not vary drastically between panel waves, with households averaging between roughly 0.85 hectares and 1.0 hectares annually.

Climate data, including the dekadal rainfall during planting, growing, and harvest periods within each season, are linked to households at the district level using the NASA Prediction of Worldwide Energy Resources (POWER) database. The POWER database includes information about precipitation, average temperature, maximum temperature, minimum temperature, humidity, and wind at a 1-degree-by-1-degree resolution. Geo-referenced centroids for each district's latitude and longitude are calculated for each of the 70 districts within the sample. In some instances, the spatial resolution within the POWER database prevents unique identification of all districts because the centroids were too close to differentiate. This results in 56 uniquely identified regions within the data.

²McIntosh, Sarris, and Papadopoulos (2013) do not, however, estimate fertilizer demand as a function of index insurance availability, as we do here.

5. A Theoretical Model of Fertilizer Adoption with and without Insurance

In this model, we consider an infinitely lived, representative agricultural household with fixed land resources that chooses its fertilizer investment, f , in any given period. Two scenarios are considered:

- *No Insurance*: Households make fertilizer investment choices in the absence of an insurance market.
- *Mandatory Insurance*: A household's purchase of fertilizer is conditional on the purchase of an index insurance contract that covers the value of fertilizer.

Utility of the household is derived from stochastic earnings from farm production. Following Hill and Viceisza (2010), farm production can be divided into two segments. First, farmers make a "base" income from production on their land that is not dependent on weather conditions; this income can be considered the minimum income a household would make in the event of a catastrophic weather event. Second, farmers can choose to invest in an input, fertilizer, that may increase farm income; this additional income from fertilizer investment, is, however, weather dependent. Households begin each period with the knowledge of their current realized income (which depends on previous fertilizer investment choices) and choose a level of fertilizer investment to maximize the expected, discounted present value of lifetime utility of wealth.

For the household's dynamic optimization problem, the single, continuous state variable is a household's disposable wealth. To characterize such wealth, define \tilde{y} as stochastic income from farming with predetermined fertilizer use f , for $f \geq 0$, where income – part of which is dependent on weather, θ ³ – is decomposed as:

$$\tilde{y} = y_b + \theta g(f)$$

Base income, y_b , is independent of weather conditions, while weather-dependent income is characterized by a production function, $g(f)$, that is increasing in f . Without access to insurance, the household's next-period wealth depends only on the next realization of farm income. This transition function can be expressed as:

$$w' = y_b + \theta' g(f') \tag{1}$$

However, when insurance is tied to the purchase of fertilizer, the transition function for wealth changes slightly to incorporate the possibility of a household being indemnified in the case of adverse weather. Thus, the expression for next period's wealth under the insurance scenario becomes:

$$w' = y_b + \theta' g(f') + \theta' p f' \tag{2}$$

Define $h(\theta) = \theta' p f'$ as the indemnity function.

Additional model parameters are:

1. $\rho \equiv$ the probability of a catastrophic weather event (e.g., a drought), so that a farm household experiences normal crop conditions with probability $(1 - \rho)$.
2. $\pi \equiv$ insurance premium (where insurance is required for fertilizer purchase).

Specifically, the premium for index insurance that covers the value of the fertilizer investment is:

$$\pi = (1 + \lambda)\rho p f'$$

where λ is the premium load. Thus $\lambda = 0$ reflects the case of actuarially fair insurance; $\lambda > 0$ reflects actuarially unfavorable insurance (which is common in practice in private markets, as insurers must account for transactions and ambiguity costs in order to break even); and $\lambda \in [-1, 0)$ reflects subsidized insurance, where a negative premium load is usually associated with government-run or donor-sponsored insurance projects – especially those in the pilot phase.

³For simplicity, we denote $\theta = 1$ as representing good weather and $\theta = 0$ as representing bad weather.

3. $p \equiv$ price per unit of fertilizer.

4. $\delta \in (0, 1] \equiv$ the farm household's time discount factor.

The farm household's dynamic optimization problem can now be expressed in the form of a single Bellman equation (one for each scenario) whose value function represents the maximum expected present value of lifetime utility, $V(w)$, given the household's predetermined fertilizer investment, f . To summarize, under no insurance, households purchase fertilizer and do not recoup any of their investment should an adverse weather shock occur. Under mandatory insurance, fertilizer-purchasing households incur the fertilizer investment cost, plus the additional cost of an index insurance premium; however, under poor weather conditions, the index insurance contract indemnifies the farm household in the amount of the fertilizer investment.

Recalling the state transition functions for w , the household's Bellman equations take the form:

$$V(w) = \text{Max}_{f' \geq 0} \left\{ u(w - pf') + \delta E_{\bar{\theta}} V(w') \right\} \quad (3)$$

$$V(w) = \text{Max}_{f' \geq 0} \left\{ u(y_b + \theta g(f) - pf' + (1 - \theta)h - \pi) + \delta E_{\bar{\theta}} V(w') \right\} \quad (4)$$

While we reserve the estimation of this structural model of fertilizer choice as a topic for future work, it is important to consider that farm households make input decisions in a dynamic – and not a static – environment. Thus, the use of static expected utility theory models may under- or over-estimate household-level demand for fertilizer.⁴

6. Conceptual Framework

6.1. Empirical Model

Agricultural households are expected to use fertilizer when they expect to receive higher yields (and higher profits) from using the fertilizer compared to yields without fertilizer use. All else equal, more income leads to greater levels of utility, and, therefore, the decision can be modeled under a random utility framework where households maximize utility and decide to use fertilizer when they receive greater utility from fertilizer use relative to non-use (deJanvry, Dustan, and Sadoulet, 2010; Asfaw et al., 2012). Each household, i , faces the binary decision to use fertilizer $F^* \in \{0, 1\}$, given constraints and household characteristics modeled as:

$$F_i^* = \mathbf{X}_i \beta + \varepsilon_{1i} \quad (5)$$

where \mathbf{X} represents a vector of covariates affecting the household fertilizer use decision, β represents regression parameters, and ε_{1i} is the error term. The latent choice to use fertilizer (Equation 5) is not directly observed. Instead, observed fertilizer use occurs when the latent propensity to use fertilizer is positive ($U_{iA} - U_{iN} > 0$). Therefore, the observed adoption decision can be expressed in terms of its latent counterpart as:

$$F_i = \begin{cases} 1 & \text{if } F_i^* > 0 \\ 0 & \text{if } F_i^* \leq 0 \end{cases} \quad (6)$$

Unlike many binary input decisions, such as improved seed or irrigation, once a household decides to use fertilizer it must also make the subsequent decision to determine the amount of fertilizer to use. This means that the amount of fertilizer demanded can be modeled by a set of observable and unobservable characteristics. Input factor demand can be modeled as:

$$D_{fert} = D(E(\mathbf{P}), \mathbf{Z}, \mathbf{X}) \quad (7)$$

⁴Miranda and Farrin (2012) note that the same is true for index insurance demand among risk-averse farmers; if credit and savings are available, observed demand for insurance will be less than what is predicted by static von Neumann-Morgenstern expected utility theory.

where $E(\mathbf{P})$ is a vector of expected crop prices that are not directly observable by the household until the next harvest, meaning that all production decisions, including fertilizer use, occur prior to their realization. Two other vectors influence fertilizer demand: \mathbf{X} consists of input prices, such as agricultural wages and fertilizer costs, while \mathbf{Z} is a vector of household, locational, and agro-ecological characteristics that affect production. Fertilizer is primarily used for maize production; changes in price expectations for other crops would affect the amount of land farmers allocate to maize, which would therefore influence fertilizer demand.

The two decisions are modeled jointly under a “double hurdle” model (Cragg, 1971). In a traditional Tobit model, the same set of covariates affects the fertilizer use decision as well as the quantity of fertilizer demanded. Parameter estimates are restricted to having the same sign and magnitude for both decisions. The double hurdle model relaxes these assumptions and provides additional flexibility when estimating a censored model. This type of model decouples the two decisions, and households first make the decision to use fertilizer and then choose the optimal quantity – which can even be zero. The initial binary fertilizer use decision is estimated as a Probit model, and a truncated normal model is then used to estimate the quantity demanded. The log likelihood function for the double hurdle model is

$$\begin{aligned} \mathcal{L} = & \sum_{y_i=0} \left[\log \left\{ 1 - \Phi \left(z_i \gamma, \frac{x_i \beta}{\sigma}, \rho \right) \right\} \right] \\ & + \sum_{y_i>0} \left(\log \left[\Phi \left\{ \frac{z_i \gamma + \frac{\rho}{\sigma} (y_i - x_i \beta)}{\sqrt{1 - \rho^2}} \right\} \right] - \log \sigma + \log \left\{ \phi \left(\frac{y_i - x_i \beta}{\sigma} \right) \right\} \right) \end{aligned} \quad (8)$$

The empirical specification includes independent variables in both the fertilizer use and fertilizer application equations. The econometric analysis helps identify characteristics linked to fertilizer use and higher levels of application. Variables employed in the model specification and expected effects on both equations are discussed in light of previous research.

Both components of the log likelihood function – the fertilizer use and fertilizer application equations – include many head-of-household characteristics such as age, education level, and gender. Older heads of household are expected to be less likely to use fertilizer due to lower technology adoption rates (Adesina and Zinnah, 1993; Langyintuo and Mungoma, 2008). Higher levels of education are expected to lead to increased fertilizer adoption (Marenya and Barrett, 2009; Morris et al., 2007). Female-headed households face different problems when acquiring improved agricultural technologies compared to male headed households, which is expected to lead to lower fertilizer use (Doss, 2006; Doss and Morris, 2000). Other characteristics on household composition, including household size, ownership of livestock, land holdings, and gross income, are also included in the adoption equation. Larger households are expected to have higher propensities to adopt fertilizer (Minten, Koru, and Stifel, 2013). Households with larger land holdings and higher incomes (two measures of household wealth) are both expected to have higher adoption rates relative to poorer farmers.

The effect of household characteristics on fertilizer application rates is less clear. It is left as an empirical question whether older household heads that do use fertilizer apply more or less fertilizer per hectare. In a previous study, heads with higher education also show higher (though statistically insignificant) fertilizer application rates (Marenya and Barrett, 2009). However, female-headed households are also expected to apply less fertilizer per hectare relative to male-headed households (Quisumbing, 2010). Household size, ownership of livestock, and gross income are included in this equation as well. In terms of application, larger land holdings likely lead to less fertilizer per hectare as households choose a fixed amount of fertilizer without factoring land holdings into account (Xu et al., 2009b).

Two types of fixed effects are included in the current pooled econometric specification. The first are two indicator variables for 2004 and 2008. These indicators detect differences in fertilizer adoption and fertilizer application compared to the original supplemental survey administered in 2001. Two interaction terms, between the amount of hectares planted and the panel-year indicator variables, are also included in the fertilizer per hectare equation. These interaction terms are included to attempt to detect any structural changes that might be occurring exogenously between years, such as improvements in seed. Province-level fixed effects are also included in both models to account for unobserved provincial differences in fertilizer use and application that might influence either decision.

6.2. Designing an Index Insurance Product

To design the index insurance contract, we obtain nonparametric estimates of the cumulative distribution functions for cumulative dekadal rainfall for each district.⁵ Because historical rainfall during the harvest period (April-May) is low,⁶ we use rainfall data for only the planting (November-December) and growing (January-March) periods of the season to design a single-phase, zero-one index insurance contract. To simplify the premium calculation, the contract is designed to trigger whenever rainfall is at or below the 10th quantile value. This trigger is estimated through quantile estimation (Harrell and Davis, 1982) using district-level rainfall data from 2000 to 2007. Specifically, the quantile for the cumulative proportion $P = 10$ is estimated as a weighted mean of district-level, time-series cumulative dekadal rainfall with weights

$$I_{\beta}((n+1)P, (n+1)(1-P), 1/n) - I_{\beta}((n+1)P, (n+1)(1-P), (i-1)/n)$$

where I_{β} is the cumulative beta distribution function.

The indemnity schedule is constructed so that a representative farmer is compensated for his fertilizer investment should a catastrophic weather event occur. We average the reported cost of fertilizer per hectare for households by district to come up with a payment amount. Combining the indemnity schedules with the rainfall triggers estimated for each weather zone, we have 68 unique contracts.⁷ Assuming actuarially fair pricing on the contract, recall that π is the insurance premium, which is equal to 10 percent of the value of fertilizer per hectare. In further analysis, we vary π so that it is not restricted to reflect an actuarially fair premium. Thus, as in the theoretical model, we let $\pi = (1 + \lambda)\rho p f'$, where λ is the load on the premium, ρ is the probability of drought, p is the price of fertilizer and f' is the household's chosen quantity of fertilizer purchased for the upcoming crop season. Recall that because index insurance is mandatory with fertilizer purchase, a household with nonzero fertilizer use purchases one unit of insurance per hectare of maize cultivated.

7. Results

7.1. Double Hurdle Model

Results from the pooled double hurdle model are presented in Table 2. Several characteristics are statistically significant in determining the likelihood of household fertilizer use and these results are presented in the first column of the table. Older heads of household are significantly more likely to use fertilizer (a somewhat unexpected result) and more educated heads of household are also more likely to adopt fertilizer. No difference exists between female- and male-headed households, which is consistent with other studies of fertilizer use in Zambia (Jayne and Rashid, 2013; Xu et al., 2009b). Larger households are also significantly more likely to use fertilizer. All three variables relating to wealth, including ownership of livestock, land holdings, and gross income are positive and statistically significant. Propensities for households to use fertilizer increased in both 2004 and 2008 relative the base year. Relative to the Western Province, all provincial fixed effects are statistically significant and show higher use of fertilizer.

Results for the application of fertilizer are not as significant and presented in the third column of Table 2. Only a few household characteristics are statistically significant, including larger households ($p = 0.10$), wealthier households, and interaction terms between maize planted and the panel year. Households that cultivate more land also apply significantly less fertilizer per hectare. Four of the eight provincial fixed effects are also statistically significant. It is not very easy to determine the impact of these significant variables on fertilizer use per hectare based on the parameter estimates alone for this hurdle. Instead, average partial effects are computed, discussed, and presented in Table 3. The average partial effect for most statistically significant household characteristics is small, with limited additional fertilizer per hectare being applied. Each additional household member leads to a 1.83 fertilizer (kg) per hectare increase.

⁵Note, however, that due to the proximity of some districts, the same weather data – and hence the same index insurance contract – serve multiple districts; specifically, out of 70 districts in the data, there are 56 distinct locations for the measurement of weather data.

⁶In addition, it may be the case that excessive – not deficit – rainfall in the harvest period is more likely to negatively affect production. See, e.g., Cole, Stein, and Tobacman (2011), which discusses an excess rainfall provision built into Indian index insurance contracts where heavy rain was found to damage crops near harvest time.

⁷While the weather data isn't distinct for all districts, fertilizer expenditure is, and therefore the different payment schedules result in different contracts even for districts that share the same weather data. In addition, we eliminate two districts from this exercise, Sesheke and Shangombo, as zero fertilizer sales are reported in the data for these districts.

Cultivating more land also leads to approximately 2.24 more kilograms of fertilizer per hectare. While the average partial effect for income seems extremely small, an increase in income of approximately \$25 leads to increased fertilizer use of approximately 4.4 kilograms of fertilizer per hectare. Provincial effects are much larger. Households living in the Central, Copperbelt, Luapula, and Northern provinces all apply roughly an additional 100-120 kg of fertilizer per hectare of soil compared to the Western province. The North Western province also applies more fertilizer (60 kg per hectare) than the Western province, but less than other significant regions.

7.2. Simulating Index Insurance Coverage

Using the estimated coefficients from the double hurdle model – specifically, the estimate for the effect of gross income on both fertilizer uptake and intensity – we use the corresponding weather data to determine what the hypothetical net payment (indemnity less premium) would be to a household holding a mandatory index insurance contract. We include the net insurance payment in the gross income component of the fertilizer demand equations to come up with a new likelihood of fertilizer adoption and rate of fertilizer use per hectare.

When we adjust the household's wealth to include coverage by a hypothetical index insurance contract, we find lower fertilizer use and application rates across the sample. This is because, for the available years of data, rainfall was sufficient so as to not trigger indemnity payments. Thus, households have a negative net change in wealth from index insurance purchase as they pay an upfront premium but receive no subsequent payment.

8. Conclusion and Implications

In light of the importance of increases in agricultural productivity in SSA, we explore the use of index insurance as a means to increase fertilizer use among smallholder farmers in Zambia. However, index insurance requires upfront payment of a premium, in combination with an uncertain future payoff; thus, it can be the case that liquidity-constrained, risk-averse farmers will invest less in productive inputs if the purchase of insurance coverage becomes a condition for the purchase of such inputs. Our results are similar to other studies that examine the effect of mandatory insurance on household decisions.⁸ Thus, while the current program of fertilizer subsidies in Zambia has not resulted in the desired level of expansion and intensification of fertilizer use, index insurance may not be an effective policy substitute. Future work will expand the research to simulate a series of years of “pseudo-data” for rainfall, from which we can look at long-run benefits of index insurance under our model specification (i.e., we will be able to examine how farmers would benefit in the event of an adverse weather event, despite the fact that no such event occurred in our data series). In addition, we will look at the effects of premium subsidies for index insurance contracts to compare fertilizer use and application rates across levels of subsidy.

Results of the double hurdle model of fertilizer demand show that households with older, more educated heads, larger households, and households with more land, gross income, and livestock holdings tend to be fertilizer adopters. However, we also find that more land results in a lower intensity of fertilizer application, suggesting that households who do use fertilizer tend to purchase it in fixed amounts, either spreading it out over all of their plots or only applying it to selected plots. Given a positive (although not significant) coefficient for education on fertilizer intensity, it may be the case that increased agricultural extension may result in increased intensity of fertilizer use. Because gross income has a positive and significant coefficient in both the uptake and intensity decisions for fertilizer use, the use of cash transfers and subsidized insurance (or another form of disaster aid that takes on an insurance or safety net role) may lead to larger increases in fertilizer use on both the intensive and extensive margins.

References

- Adesina, Akinwumi and Moses Zinnah. 1993. “Technology Characteristics: Farmers’ Perceptions and Adoption Decisions: A Tobit model Application in Sierra Leone.” *Agricultural Economics* 9(4):297–311.
- Alem, Yonas, Mintewab Bezabih, Menale Kassi, and Precious Zikhali. 2010. “Does Fertilizer Use Respond to Rainfall Variability? Panel Data Evidence from Ethiopia.” *Agricultural Economics* 41(2):165–175.

⁸One such article, for example, is Gine and Yang (2009), who find that credit demand declines among smallholders in Malawi when the purchase of an index insurance contract is a condition for taking out a loan.

Table 1: Summary Statistics by Year

Variable	1999/2000 Harvest		2002/2003 Harvest		2006/2007 Harvest	
	Mean	Std. Error	Mean	Std. Error	Mean	Std. Error
Household Uses Fertilizer = 1	0.272	0.445	0.354	0.478	0.366	0.482
Household Size	6.271	3.168	6.190	2.906	6.131	2.882
Head of Household Years of Education	5.154	3.664	4.999	3.739	5.129	3.681
Household Owns Livestock = 1	0.834	0.372	0.846	0.361	0.773	0.419
Total Hectares Cultivated (all crops)	1.666	1.466	1.746	1.473	1.738	1.684
Gross Income (U.S. Dollars)	540.21	899.69	637.08	1084.21	1259.31	1885.47
Female Head of Household = 1	0.203	0.402	0.217	0.412	0.232	0.422
Head of Household Age	45.014	14.854	47.625	14.766	51.761	14.792
Hectares Maize Planted	0.981	1.060	0.852	0.878	1.022	1.237
Central Province = 1	0.133	0.339	0.126	0.331	0.127	0.333
Copperbelt Province = 1	0.069	0.254	0.065	0.246	0.067	0.249
Eastern Province = 1	0.317	0.466	0.294	0.456	0.290	0.454
Luapula Province = 1	0.039	0.194	0.040	0.196	0.045	0.206
Lusaka Province = 1	0.028	0.166	0.024	0.154	0.025	0.157
Northern Province = 1	0.108	0.310	0.132	0.339	0.135	0.342
North Western Province = 1	0.057	0.232	0.074	0.262	0.069	0.254
Southern Province = 1	0.143	0.350	0.139	0.346	0.135	0.342
Western Province = 1	0.105	0.307	0.105	0.307	0.108	0.310

Note: Weighted results based on different sample sizes depending upon year because the number of households planting maize varied by year. The sample sizes are: N = 3150, N = 3355, and N = 3441 for the 1999/2000 harvest, 2002/2003 harvest, and the 2006/2007 harvest respectively.

Table 2: Double Hurdle Regression Results

Variable	Fertilizer Use		Fertilizer Intensity	
	Estimate	Std. Error	Estimate	Std. Error
Head of Household Age	0.003*	0.001	0.034	0.271
Head of Household Education Level	0.054**	0.006	1.486	0.977
Female Headed Household = 1	-0.004	0.049	-8.279	9.408
Household Size	0.019**	0.006	2.068†	1.091
Household Owns Livestock = 1	0.127**	0.048	-11.192	9.510
Total Hectares Cultivated by Household	0.090**	0.013	-16.239**	3.023
Household Gross Income (U.S. Dollars)	0.0002**	0.00002	0.013**	0.003
2004 Panel Year = 1	0.248**	0.034	60.718**	12.086
2008 Panel Year = 1	0.201**	0.039	45.970**	11.590
Maize Hectares Planted Interacted with 2004	—	—	-33.823**	8.578
Maize Hectares Planted Interacted with 2008	—	—	-10.099	6.158
Central Province = 1	1.399**	0.093	99.851**	30.972
Copperbelt Province = 1	1.316**	0.104	73.685**	31.954
Eastern Province = 1	1.106**	0.088	36.314	30.799
Luapula Province = 1	0.807**	0.114	170.650**	32.134
Lusaka Province = 1	1.461**	0.165	71.037**	33.898
Northern Province = 1	1.090**	0.095	162.483**	30.591
North Western Province = 1	0.664**	0.104	62.384	34.616
Southern Province = 1	1.003**	0.095	33.437	31.746
Constant	-2.635	0.123	108.160	36.820

*: Significant at 5 percent level

** : Significant at 1 percent level

†: Significant at 10 percent level

- Asfaw, Solomon, Bekele Shiferaw, Franklin Simtowe, and Leslie Lipper. 2012. "Impact of Modern Agricultural Technologies on Smallholder Welfare: Evidence from Tanzania and Ethiopia." *Food Policy* 37(3):283–295.
- Banful, Afua Branoah. 2011. "Old Problems in the New Solutions? Politically Motivated Allocation of Program Benefits and the "New" Fertilizer Subsidies." *World Development* 39(7):1166–1176.
- Barnett, Barry J., Christopher B. Barrett, and Jerry R. Skees. 2008. "Poverty Traps and Index-Based Risk Transfer Products." *World Development* 36(10):1766–1785.
- Benson, Todd. 1999. "Area-specific Fertilizer Recommendations for Hybrid Maize Grown by Malawian Smallholders." Report, Department of Agricultural Research and Technical Services, Ministry of Agriculture and Irrigation, Lilongwe, Malawi.
- Carter, Michael R. 2012. "Designed for Development Impact: Next Generation Approaches to Index Insurance for Smallholder Farmers." Unpublished manuscript, University of California - Davis, Department of Agricultural Economics, Davis, CA.
- Cole, Shawn, Daniel Stein, and Jeremy Tobacman. 2011. "What is Rainfall Index Insurance Worth? A Comparison of Evaluation Techniques." Unpublished manuscript, Harvard Business School, London School of Economics and Wharton School at University of Pennsylvania, Cambridge,

Table 3: Average Partial Effects

Variable	APE	Std. Error
Household Size	1.831	0.454
Total Hectares Cultivated by Household	2.244	1.168
Household Gross Income (U.S. Dollars)	0.176	0.002
2004 Panel Year = 1	32.113	4.759
2008 Panel Year = 1	25.257	4.646
Central Province = 1	121.448	8.679
Copperbelt Province = 1	109.274	9.201
Luapula Province = 1	97.973	11.401
Northern Province = 1	115.481	9.537
North Western Province = 1	61.322	10.063

Note: Standard errors are calculated using bootstrapped standard errors.
All results significant at $p = 0.05$.

MA; London, UK; Philadelphia, PA.

- Cragg, John G. 1971. "Some Statistical Models for Limited Dependent Variables with Application to the Demand for Durable Goods." *Econometrica* 39():829–844.
- deJanvry, Alain, Andrew Dustan, and Elisabeth Sadoulet. 2010. "Recent Advances in Impact Analysis Methods for Ex-post Impact Assessments of Agricultural Technology: Options for the CGIAR." Working Paper, CGIAR, Montpellier, France.
- Doss, Cheryl R. 2006. "Analyzing Technology Adoption Using Microstudies: Limitations, Challenges, and Opportunities for Improvement." *Agricultural Economics* 34(3):829–844.
- Doss, Cheryl R. and Michael Morris. 2000. "How Does Gender Affect the Adoption of Agricultural Innovation? The case of Improved Maize Technology in Ghana." *Agricultural Economics* 25(1):27–39.
- Evenson, Robert E. and Douglas Gollin. 2003. "Assessing the Impact of the Green Revolution, 1960 to 2000." *Science* 300():758–762.
- Fuglie, Keith O. and Nicholas E. Rada. 2013. "Resources, Policies and Agricultural Productivity in Sub-Saharan Africa." Economic Research Report ERR-145, Economic Research Service, USDA, Washington, DC.
- Gine, Xavier and Dean Yang. 2009. "Insurance, Credit, and Technology Adoption: Field Experimental Evidence from Malawi." *Journal of Development Economics* 89(1):1–11.
- Godfray, H. Charles J., John R. Beddington, Ian R. Crute, Lawrence Haddad, Lavid Lawrence, James F. Muir, Jules Pretty, Sherman Robinson, Sandy M. Thomas, and Camilla Toulmin. 2010. "Food Security: The Challenge of Feeding 9 Billion People." *Science* 327(1):812–818.
- Harrell, Frank E. and C.E. Davis. 1982. "A New Distribution-Free Quantile Estimator." *Biometrika* 69(3):635–640.
- Hill, Ruth Vargas and Angelino Viceisza. 2010. "An Experiment on the Impact of Weather Shocks and Insurance on Risky Investment." Discussion Paper 00974, International Food Policy Research Institute, Washington, DC.
- Jayne, Thomas, David Mather, Nicole Mason, and Jacob Ricker-Gilbert. 2013. "How do Fertilizer Subsidy Programs Affect Total Fertilizer Use in Sub-Saharan Africa? Crowding Out, Diversion, and Benefit/Cost Assessments." *Agricultural Economics* 44():687–703.
- Jayne, Thomas and Shahidur Rashid. 2013. "Input Subsidy Programs in Sub-Saharan Africa: A Synthesis of Recent Evidence." *Agricultural Economics* 44():547–562.
- Langyintuo, Augustine S. and Catherine Mungoma. 2008. "The Effects of Household Wealth on the Adoption of Improved Maize Varieties in Zambia." *Food Policy* 33(6):550–559.
- Marennya, Paswel, Vincent H. Smith, and Ephraim Nkonya. 2014. "Relative Preferences for Soil Conservation Incentives among Smallholder Farmers: Evidence from Malawi." *American Journal of Agricultural Economics* ():doi: 10.1093/ajae/aat117.
- Marennya, Paswel P. and Christopher B. Barrett. 2009. "Soil Quality and Fertilizer Use Rates among Smallholder Farmers in Western Kenya." *Agricultural Economics* 40(5):561–572.
- Marinho, Eduardo. 2004. "Fertilization Strategies and Spatial Risk Reduction." Mimeo, Université Catholique de Louvain, Louvain-la-Neuve, Belgium.
- Mason, Nicole M. and Thomas S. Jayne. 2013. "Fertiliser Subsidies and Smallholder Commercial Fertiliser Purchases: Crowding Out, Leakage and Policy Implications for Zambia." *Journal of Agricultural Economics* 64(3):558–582.
- Mason, Nicole M., Thomas S. Jayne, and Rhoda Mofya-Mukuka. 2013. "Zambia's Input Subsidy Programs." *Agricultural Economics* 44():613–628.
- McIntosh, Craig, Alexander Sarris, and Fotis Papadopoulos. 2013. "Productivity, Credit, Risk and the Demand for Weather Index Insurance in Smallholder Agriculture in Ethiopia." *Agricultural Economics* 44():399–417.
- Megill, David J. 2005. "Recommendations for Adjusting Weights for Zambia Post-Harvest Survey Data Series and Improving Estimation Methodology for Future Surveys." Working Paper, Indaba Agricultural Policy Research Institute, Lusaka, Zambia.
- Minot, Nicholas and Todd Benson. 2009. "Fertilizer Subsidies in Africa: Are Vouchers the Answer?" Issue Brief 60, International Food Policy Research Institute, Washington, DC.
- Minten, Bart, Bethlehem Koru, and David Stifel. 2013. "The Last Mile(s) in Modern Input Distribution: Pricing, Profitability, and Adoption." *Agricultural Economics* 44(6):629–646.
- Miranda, Mario J. and Katie Farrin. 2012. "Index Insurance for Developing Countries." *Applied Economic Perspectives and Policy* 34(3):391–427.
- Morris, Michael, Valerie A. Kelly, Ron J. Kpicks, and Derek Byerlee. 2007. *Fertilizer Use in African Agriculture: Lessons Learned and Good Practice Guidelines*. Washington, DC: The World Bank.
- Quisumbing, Agnes R. 2010. "Promising Approaches to Address the Needs of Poor Female Farmers: Resources, Constraints, and Interventions." *World Development* 38(4):581–592.

- Ricker-Gilbert, Jacob, Thomas S. Jayne, and Ephraim Chirwa. 2011. "Subsidies and Crowding Out: A Double-Hurdle Model of Fertilizer Demand in Malawi." *American Journal of Agricultural Economics* 93(1):26–42.
- Ricker-Gilbert, Jacob, Nicole M. Mason, Francis A. Darko, and Solomon T. Tembo. 2013. "Whart are the Effects of Input Subsidy Programs on Maize Prices? Evidence from Malawi and Zambia." *Agricultural Economics* 44(6):671–686.
- Rosenzweig, Mark R. and Hans P. Binswanger. 1993. "Wealth, Weather Risk and the Composition and Profitability of Agricultural Investments." *The Economic Journal* 103(416):56–78.
- Smale, Melinda and Ekin Birol. 2013. "Smallholder Demand for Maize Hybrids and Selective Seed Subsidies in Zambia." HarvestPlus Working Paper 9, International Food Policy Research Institute, Washington, DC.
- Xu, Zhiying, William Burke, Thomas Jayne, and Jones Govereh. 2009a. "Do Input Subsidy Programs "Crowd In" or "Crowd Out" Commercial Market Development? Modeling Fertilizer Demand in a Two-Channel Marketing System." *Agricultural Economics* 40(1):79–94.
- Xu, Zhiying, Zhengfei Guan, Thomas S. Jayne, and Roy Black. 2009b. "Factors Influencing the Profitability of Fertilizer Use on Maize in Zambia." *Agricultural Economics* 40(4):437–446.