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Hybrid Seed and the Economic Well-Being of Smallholder Maize Farmers in Zambia

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ABSTRACT *The development and diffusion of hybrid maize in Zambia since the 1970s is a major achievement in African agriculture, but other than profitability studies, analyses of how this process has affected the economic well-being of smallholder farmers have been few. We test the relationship of hybrid seed use with six indicators of economic well-being. After using the control function/instrumental variables approach to test for the endogeneity of hybrid seed use, we estimate correlated random effects (CRE) fractional response, CRE Tobit, and fixed effects models with a panel of nationally representative data collected in 2002/3 and 2006/7. Findings suggest that use of maize hybrids is associated with higher values of household income, assets, farm and processing equipment, and livestock, and less deprivation compared to other farmers in nearby villages.*

1. Introduction

The successful development and diffusion of improved maize in Zambia represents a major scientific and policy achievement in African agriculture (Howard, 1994; Howard & Mungoma, 1997; Smale & Jayne, 2010). The commitment of the Government of Zambia (GoZ) to ensuring food security has played a pivotal role in realising maize productivity gains on smallholder farms. On the one hand, this commitment has taken tangible form as a long-term investment in maize research and development and seed market liberalisation from the 1990s. Zambia can boast a larger number of seed companies compared to other maize-reliant nations in the region (Kassie et al., 2013); five of these are major companies that finance their own seed research. On the other hand, the GoZ has provided inputs and services to maize growers via subsidy programmes and maize price controls, initially during the 'boom' period of 1970–1989, and again from 2002, with the expressed goals of rebuilding the resource base and instilling a sense of self-reliance among smallholders (MACO, 2008).

Although a number of insightful case studies about the adoption of maize hybrids among smallholder farmers have been conducted in Zambia, we know of no nationally representative analyses focused on estimating the relationship between hybrid seed use and economic well-being of smallholder maize growers in Zambia. During the late 1980s, survey-based research conducted by the International Food Policy Research Institute (IFPRI) in the Eastern Province of the country explored fertiliser use and gender aspects of hybrid seed use (Jha & Hojjati, 1993; Kumar 1994). More recently, case study, survey-based research was conducted by the Zambian Agricultural Research Institute (ZARI) and the International Center for Maize and Wheat Improvement (CIMMYT). Langyintuo and Mungoma (2008) concluded that the factors influencing both the adoption and use intensity of

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improved maize seed differed by wealth group. Kalinda et al. (2010) and Hamazakaza, Smale, & Kasalu (2013) also found that better-off households grew more improved maize varieties.

Recently, researchers have analysed the impacts of maize seed and fertiliser subsidy programmes in Malawi and Zambia (Chibwana, Fisher, & Shively, 2012; Mason & Ricker-Gilbert, 2013), adding to a relatively long history of literature about adoption of improved maize seed in neighbouring Malawi (for example, Diagne & Zeller, 2001; Lunduka, Fisher, & Snapp, 2012; Simtowe, Zeller, & Diagne, 2009; Smale, Heisey, & and Leathers, 1995). Malawi shares a similar agro-climate and political legacy with Zambia from the colonial period, when both were members of the Federation of Rhodesia and Nyasaland. In East Africa, recent analysis of the impacts of hybrid seed on Kenyan smallholders (Mathenge, Smale, & Olwande, 2014) builds on in-depth adoption research conducted by Suri (2011). Most of these studies, however, explore the determinants of adoption of hybrid maize, rather than its association with economic well-being. Diagne and Zeller (2001) explored the role of credit constraints in access to improved seed and fertiliser, and its relationship with net crop income for maize and tobacco. Mathenge, Smale, & Olwande (2014) found the influence of hybrid seed on income and assets to be favourable for smallholder maize growers in Kenya.

While we might expect that hybrid seed use is associated positively with economic well-being of smallholder maize growers on average and over the longer term, we are also aware of the heterogeneity within this population and the possibility that, especially in the initial years of hybrid seed use, and in less favourable environments with less well-adapted seed, growing hybrid maize is not always profitable. Our contribution to the literature is to measure and rigorously test the quantitative association between hybrid seed use and indicators of economic well-being among smallholder maize growers in Zambia. We define well-being in terms of six indicators: total household income; the severity of poverty; the value of total productive assets; the value of farm and processing equipment; the number of total livestock units owned; and relative deprivation with respect to total assets. We examine our research questions with data drawn from a nationally representative, longitudinal sample of 3,231 smallholder maize growers in Zambia during the 2002/3 and 2006/7 agricultural seasons. We estimate correlated random effects (CRE) fractional response, CRE Tobit, and fixed effects (FE) models to measure the relationship between a 1 kg increase in hybrid maize seed planted and each of the six indicators of economic well-being.

Panel data methods employed (CRE and FE) control for *time-invariant* unobserved effects that may be correlated with both hybrid seed use and the indicators of economic well-being, but hybrid seed use could also be correlated with *time-varying* unobserved effects that influence the indicators. We test for the potential endogeneity of hybrid seed use via the control function/instrumental variables approach (Smith & Blundell 1986; Vella 1993). Following Mathenge, Smale, & Olwande (2014), our instrument is the cumulative adoption rate in the district, measured as the percentage of smallholder maize area that is planted to F1 hybrids in the previous season. Constructed from secondary data, pre-determined and based on the decisions of thousands of households, the variable is beyond the control of individual farmers (and unlikely to be correlated with household-level, time-varying unobserved heterogeneity). Statistical tests lead us to fail to reject the null hypothesis that hybrid seed use is exogenous to the economic well-being of smallholder maize growers. Given the difficulty of definitively establishing causality, however, we describe our regression results as associations and correlations rather than impacts or causal effects.

The next section presents the conceptual approach, data and econometric methods. Findings are presented in the third section, including selected descriptive statistics and regression estimates. In the fourth section, we draw conclusions and policy implications.

2. Methods

2.1 Conceptual Approach

We view seed choices of smallholder farmers in Zambia from the viewpoint of the non-separable model of the household farm, in which family members organise their labour to maximise utility over consumption goods and leisure in an economic environment with market failures (de Janvry Fafchamps, & Sadoulet, 1991; Singh, Squire, & Strauss, 1986). Households produce goods for consumption or sale, and cash constraints are relaxed primarily through farm sales and off-farm employment of family members. When consumption decisions cannot be separated from production decisions, effective decision prices are endogenous and influenced by observed market prices and household characteristics. Capital endowments, including human capital, affect demand for hybrid seed through their influence on transactions costs and consumption preferences.

Zambian smallholders have grown maize hybrids since the late 1970s (Howard, 1994; Howard & Mungoma, 1997; Smale & Jayne, 2010). Growing higher-yielding hybrid maize can contribute to increasing incomes and reducing poverty through annual effects on cash earned through additional sales of maize or other crops grown on land re-allocated from maize because of higher yields. The asset base of the household can grow as income is accumulated and capitalised. Over time, households growing hybrids may be ranked more highly in their communities with respect to income and/or assets relative to the period before adoption. On the other hand, in an increasingly diversified agricultural economy, as households move away from reliance on maize production and meet consumption needs through other income sources, we might expect the use of hybrid seed to matter less as a component of total household income. In that case, we would hypothesise a weak relationship between hybrid seed use and income, poverty, or assets. Furthermore, the wide variation in the profitability of hybrid maize use among heterogeneous smallholders suggests that a significant association between it and income, poverty and asset values may not always be discernible at the mean (see Suri [2011] for Kenya).

From a large body of previous empirical research on the adoption of agricultural technologies, we hypothesise that adopters are generally those who are wealthier in terms of various types of capital (human, natural, physical) and have more access to soft (information and financial services) and hard (roads, vehicles and marketplaces) market infrastructure. Thus, any estimate of the relationship of hybrid seed with indicators of economic well-being that does not take this into account may exhibit a bias due to the underlying effects of these factors. This bias, attributable in our case to self-selection through seed choice, reflects the fact that adopters may be better off than non-adopters even before they adopt.

Thus, we consider that either because of selection on observables (for example, farm size, education, labour supply) or unobservables (for example, intrinsic management ability, unmeasurable soil quality), simultaneity in decision-making or feedback processes, the decision by Zambian smallholder farmers to grow hybrid maize seed is potentially endogenous in the indicators of economic well-being that we investigate. Particular features of the data we employ, and the construction of the indicators, raise other methodological considerations that are relevant to the specification of the econometric models. These are summarised below.

2.2 Data

The data were collected using a nationally representative sample of smallholder farm households in 70 districts of Zambia. The sampling frame was designed by the Zambian Central Statistical Office (CSO) and the survey was conducted as a supplement to the Post-Harvest Survey by the CSO, Ministry of Agriculture and Cooperatives (MACO) and Food Security Research Project of Michigan State University (see Megill [2005] for further details on the sampling frame.) In the first wave of the survey (1999/2000), which is not used here because maize seed details were not recorded, a total of 6,922 smallholder farmers were interviewed. During the second wave, covering the 2002/03 agricultural year, a total of 5,358 households were re-interviewed. Of these, 4,286 were re-interviewed in the 2006/07 agricultural year.

Only maize-growing households were used in the current study, numbering 3,553 and 3,542 in the latter two survey waves respectively. In the econometric analysis, only the balanced panel of 3,231 households which grew maize in both 2002/3 and 2006/7 is utilised. Burke (2012) used the same sample of maize-growing households and finds that excluding households that grew maize in only one of the two years does not result in sample selection bias. Attrition bias may also be a source of concern, but there is no regression-based test for attrition bias when FE or CRE models are employed with two time periods only. A minimum of three time periods is required for such tests. Earlier research (Mason, 2011) based on the same data set but using all three waves of data found no evidence of attrition bias when the regression-based test specified in Wooldridge (2010) was applied. The regression models in our analysis control for attrition bias to the extent that it is related to the observed covariates and/or time-constant, unobserved effects (Mason and Ricker-Gilbert, 2013).

The instrumental variable, district-level cumulative adoption of hybrid maize is constructed using data from the 2001/02 and 2005/06 CSO/MACO Post-Harvest Surveys. These survey data are nationally representative of smallholder farm households and capture the year before each of the two waves of panel survey data used in the analysis.

2.3 Indicators of Economic Well-Being

We consider six indicators of the economic well-being of smallholder maize-growing households: (1) total household income; (2) the severity of poverty; (3) the value of total productive assets; (4) the value of farm and processing equipment; (5) the total number of livestock units (TLUs) owned; and (6) relative deprivation with respect to total productive assets.

Household income includes crop income (gross value of crop production); livestock income (gross value of livestock products); salaries, formal/informal wage income, and business income for household members; and remittances, pensions and share dividends received by all household members. Thus, as compared to maize yields and net income in maize production, we focus our research interest on broader ('higher level') indicators of economic well-being among smallholder maize growers. We use gross income because of the significance of allocable labour inputs among crops, which were not measured in the raw data, as well as the endogeneity of input and produce prices in the non-separable model. Observed market prices are included as determinants of outcome variables in our regression models. Values are expressed in nominal terms, and we include a dummy variable for 2006 to control for the effects of inflation.

We measure the severity of poverty based on the Foster–Greer–Thorbecke (Foster, Greer, & Thorbecke, 1984) index:

$$FGT_{\alpha} = (1/n)\sum_{i=1}^{h}\left(\frac{z-y_i}{z}\right)^{\alpha} \tag{1}$$

where α =2 and h is defined for households with income (y_i) below the poverty line (z). To compute the poverty line for each household, we use the current Zambia kwacha (ZMK) divided by the current international dollar (PPP), multiplied by the World Bank poverty rate ($2.00 per capita per day), 365 days, and household size. We then compare annual household income to the poverty line, divide by the poverty line, and square the result. Although the Foster-Greer-Thorbecke (FGT) is typically applied as a summary measure (for example, an average), in order to use it in regression modelling we construct the household-specific value of the index according to the expression within the summation sign. The meaning of the index, however, does not change, and the regression coefficients can be interpreted as average effects.

Household total productive assets include farm and agrifood processing equipment, transport vehicles and large livestock (cattle, pigs, goats, sheep, and donkeys) – see Online Appendix Table A1 for a complete list of the non-livestock productive assets included. The farm and processing equipment variable includes ox carts but excludes other transport vehicles (bicycles, cars, trucks). Values are measured in nominal ZMK and are as of approximately one year after the household harvested maize (for example, asset values as of June/July 2008 for maize planted during the 2006/07 agricultural year and harvested in mid-2007). Our particular interest in the equipment variable is to explore the relationship of hybrid seed adoption to investments in assets that are of immediate use in crop production.

Livestock is widely known to be the principal way that many households in sub-Saharan Africa accumulate and store their wealth, and this is also the case in rural Zambia. Densely populated, major maize-producing areas of Zambia also have high densities of cattle and small ruminants (FAO/AGAL

2005). Half of maize-growing households in our sample owned at least one unit of livestock on the hoof (almost all owned chickens or other fowl, which we did not include). For comparative purposes, in order to use a physical measure of livestock wealth, we converted the livestock outcome variable to standard livestock units rather than values. Total livestock units are computed by multiplying the numbers owned in each category of livestock by FAO's recommended coefficients (cattle=0.5, sheep and goats=0.1, and pigs=0.2 [FAO/AGAL, 2005]). For donkeys, we used the figure reported by Jahnke (1982, p. 10): 0.5.

As with the FGT indices, popular measures of inequality, such as the Gini or Theil indices, are also calculated over a distribution of households or individuals. People often compare themselves with others in their immediate reference group, such as a village, rather than with the whole society (Yitzhaki, 1979). Based on this observation and their analysis of the effects of migration on households in Mexico, Stark & Taylor (1989) proposed an index calculated at the individual or household level and given as:

$$RD(Y_i) = AD(Y_i) * P(Y_i) \tag{2}$$

We calculated the relative deprivation $RD(Y_i)$ index for each household i with respect to the value of total productive assets (Y_i). The remaining households in the sample drawn from the same standard enumeration area (SEA) are used as the reference group. The SEA is the primary sampling unit of the national sampling frame designed by the Central Statistical Office of Zambia, defined to be roughly constant in population size and representation. An SEA contains approximately 150–200 households, or two to four villages. $AD(Y_i)$ is the mean value of productive assets of households in the SEA with more productive assets than a given household i and $P(Y_i)$ is the proportion of households in the SEA that have more productive assets than a given household i (Stark & Taylor, 1989). To construct the index, households within an SEA were ranked by productive assets from highest to lowest. The higher the value of $RD(Y_i)$, the greater is the deprivation of the household relative to other households in their SEA.

2.4 Econometric Models

We apply panel data methods to estimate separate regressions for each outcome variable of interest according to the following general model:

$$Y_{it} = \beta_0 + \boldsymbol{X}_{it}\boldsymbol{\beta}_1 + \gamma Z_{it} + \alpha_i + u_t + \varepsilon_{it,} \text{ where } i = 1,..,N \quad t = 1,..,T. \tag{3}$$

The dependent variable Y is the outcome indicator of interest, $\boldsymbol{X}$ is a vector of exogenous explanatory variables, Z is hybrid seed use in kilograms, i indexes the household and t indexes the year. The composite error terms consists of time invariant unobserved heterogeneity (α_i), a time fixed effect (u_t), and the idiosyncratic error, which varies over households and over time (ε_{it}).

The estimator used for Equation (3) varies by dependent variable. When the dependent variable is continuous, as in the case of the outcomes measuring household income and relative deprivation, we apply the fixed effects (FE) estimator. The total value of assets, value of farm and processing equipment, and total number of livestock units are corner solution variables. These variables are equal to zero for maize growers who do not own the assets and positive and continuous for asset-owning households. We use Tobit models with correlated random effects (CRE) to estimate the effects of hybrid seed use on these outcomes. Finally, the poverty severity outcome is confined to the [0,1] interval but is continuous within that interval. We use a fractional response probit with CRE to estimate this model (Papke & Wooldridge, 1996, 2008). Both the FE estimator and the CRE approach allow us to control for time-invariant unobserved heterogeneity (α_i) in Equation (3). To implement the CRE approach (Chamberlain, 1984; Mundlak, 1978), household means of time-varying, observed covariates are included as additional regressors in the model. Like the FE estimator, the CRE approach requires that the regressors be strictly exogenous conditional on the observed covariates and the unobserved time-invariant heterogeneity.

Strict exogeneity is a reasonable maintained hypothesis for most of the explanatory variables in Equation (3), which are discussed in detail below. However, as noted above, we hypothesise that hybrid seed use (Z) may be endogenous in the equations predicting economic well-being. The quantity of hybrid seed planted is also a corner solution variable, since a substantial share of households do not use hybrid seed. To test the endogeneity of hybrid seed use, we employ the control function (CF)/instrumental variables approach (Smith & Blundell, 1986; Vella, 1993). This entails a two-stage estimation procedure. In the first stage, we estimate a reduced-form, CRE Tobit model explaining the amount of hybrid seed planted. The explanatory variables include the $\boldsymbol{X}_{it}$ from the structural Equation (3) and at least one instrumental variable. The instrumental variable must be strongly partially correlated with hybrid seed use but uncorrelated with ε_{it} in Equation (3). In the second step, the generalised residual from the first stage regression is included as an additional explanatory variable in the structural model (Equation 3), for each outcome variable. A t-test of the generalised residual tests the null hypothesis of exogeneity against the alternative hypothesis of endogeneity (Wooldridge, 2012).

2.5 Explanatory and Instrumental Variables

Explanatory variables, including the instrumental variable, are shown in Table 1.

Our instrumental variable in all models is the cumulative adoption rate for hybrid maize, measured from secondary data as the percentage of smallholder maize area in the district planted to F1 hybrids in the year preceding the sample survey. The instrumental variable reflects the decisions of thousands of households in the previous season, and is therefore exogenous to the seed choice of an individual household in the sample survey. More intuitively, the scale of adoption in a district proxies for the extent of information about maize hybrids available to farmers. As demonstrated in the historical literature about the Green Revolution, farmers both 'learn by doing' and 'learn from others' in the process of adopting new technologies (Feder & Slade, 1984; Foster & Rosenzweig, 1994).

The cumulative adoption rate is a valid instrument because: (a) it is statistically significant and positive in the reduced form CRE Tobit regression for hybrid seed use by farm households in the current year (as we will demonstrate below); and (b) it should be uncorrelated with unobserved time-varying shocks to the outcome indicators, especially after controlling for the observed covariates, time fixed-effect, and time-invariant unobserved heterogeneity.

The explanatory variables included in Equation (3) are selected following the underlying conceptual framework of decision-making on the household farm. Determinants of seed demand include household and market characteristics that influence shadow prices, as well as observed prices, and agro-environmental parameters that influence choices through crop production conditions. Farmgate seed prices were not collected in the survey, and only national seed prices are available for analysis. These are perfectly collinear with the year dummy included in the model. We use a year dummy to capture between year variation, and market access variables to exploit cross-sectional variation in seed prices.

Variables that capture household characteristics include proxies for human capital, or labour quality (education of the household head, maximum education of prime-age adults in the household) and labour quantity (the number of adults in the prime-age category, 15–59 years). A dummy variable tests the importance of female as compared to male headship, which past research in Zambia suggests is an important parameter for access to goods and services, resources and information. Asset endowments, excluding those included in our dependent variables, are measured by farm size. To control for the role of other household income sources using exogenous variables, we include explanatory variables measuring non-farm employment income and wages from work on other farms at the SEA level per household. These variables provide an indication of the reliance on off-farm employment in the household's community and among neighbouring communities, which may also affect the labour allocation and cash earnings of individual households.

Market characteristics are measured by a vector of price variables (maize, competing crops, fertiliser and wage), each in logarithmic form and measured at scales higher than the household, along with

Table 1. Variable definitions

Variable	Definition
Dependent variables	
Income	Total value of farm and non-farm income ('000 ZMK, nominal)
Poverty severity	Foster–Greer–Thorbecke index of poverty severity
Total assets	Total value (ZMK nominal) of productive assets (see text and the Online Appendix for details)
Farm/processing equipment	Total value of all farm and processing equipment (see the Online Appendix for details)
Total livestock units (TLUs)	Total livestock units (see text for details)
Relative deprivation (assets)	Stark–Taylor index of relative deprivation with respect to total assets, considering all other sample households in the standard enumeration area (SEA)
Explanatory variables	
Kgs hybrid	Kgs of F1 hybrid seed in survey year
Distance to district town	Kms from centre of sea to nearest district town
Distance to tarmac road	Kms from centre of sea to nearest tarred/main road
Distance to feeder road	Kms from centre of sea to nearest feeder road
Distance to transport	Kms from homestead to nearest point to get vehicular transport
Female household head	1=household headed by female, 0 otherwise
Education of head	Education of household head (years)
Maximum adult education	Maximum years of education of adults 15–59 years
Adults 15–59 years	Number of adults in prime age group (15–59 years)
Farm size	Total farm size in hectares
Crop concentration	Herfindahl index (SEA sum of squared shares of each crop in total crop income)
Non-farm earnings	Non-farm income (SEA ZMK per household, business/informal; salaried; remittance)
Labour on other farms	Income from labour on other farms (sea ZMK per household)
Rainfall	Growing season rainfall (mm, Nov.–Mar.)
Rainfall stress	Rainfall stress (no. of 20-day periods, Nov.–Mar., with <40 mm total rainfall)
Expected rainfall	5-yr. average growing season rainfall (Nov.–Mar., '00 mm)
Rainfall cv	Coefficient of variation of 5 year growing season rainfall (nov.-mar., %)
Maize price	Log of lagged price of maize, measured at the district level
Groundnut price	Log of lagged price of ground nuts, measured at the provincial level
Mixed bean price	Log of lagged price of mixed beans, measured at the provincial level
Sweet potato price	Log of lagged price of sweet potatoes, measured at the provincial level
Weeding wage	Log of wage to weed 0.25 ha field, measured at the SEA level
Fertiliser price	Log of commercial fertiliser price, measured at the district level
2006	1=agricultural year is 2006/7, 0 otherwise
Instrumental variable	
Cumulative adoption	Cumulative adoption rate in preceding season (percentage of smallholder maize area in district under F1 hybrids, year t–1)

Notes: ZMK=Zambian Kwacha; SEA=standard enumeration area, usually including survey village and several adjacent villages.

distances to district town, feeder road, tarmac road and vehicular transport. Output prices are lagged, corresponding to a naïve price expectations model.

Agro-environmental factors are included as actual rainfall and rainfall stress in the agricultural year of the survey, since this will affect the outcome variables. Also included are expected rainfall (measured as mean rainfall over the past five years) and the coefficient of variation over the same period, which affect input decisions via expectations. The rainfall variables were computed from dekadal (10-day) data obtained from the Zambia Meteorological Department from 36 weather stations throughout the country. Reflecting the fact that there are 70 districts covered in the dataset but only 36 weather stations, values for other districts are interpolated from the nearest stations based on guidance from the Meteorological Department. As a proxy for the farming system, we include the Herfindahl index of the concentration of area shares among crops, calculated at the SEA scale to ensure exogeneity.

3. Findings

3.1 Descriptive Statistics

The percentages of maize-growing households planting hybrid seed and amounts planted in the two study years are summarised in Table 2. Over a third (37%) of smallholder maize growers in 2002/3, and 43 per cent in 2006/7, planted hybrid seed. The mean amount planted by hybrid seed users rose significantly between the two survey years.

Means of each indicator variable are compared between maize growers who planted and did not plant hybrid seed, by survey year, in Table 3. Bivariate statistics provide strong evidence that maize growers who did not plant hybrid seed are economically disadvantaged relative to those who do. For example, in 2002/3, on average, total household income is nearly three times as high among maize growers who planted hybrid seed. In 2006/7, average household income is more than three times as high among hybrid maize growers. The mean severity of the poverty is greater among smallholder maize growers who do not plant hybrid seed (0.56 vs 0.41). The average total value of their assets is less than half that of hybrid seed users (1.8 vs 4.7 mill ZMK), and the mean value of their farm and processing equipment is less than a quarter that of adopters (0.17

Table 2. Hybrid seed use by smallholder maize farmers in Zambia, 2002/3 and 2006/7

	Plant hybrid seed (%)**			
	No	Yes	All	Mean kgs planted by users***
2002/3	62.6	37.4	100	33.7
2006/7	57.4	42.6	100	39.3
Both survey years	59.9	40.1	100	36.7

Notes: N = 6,462. **Use rates differ significantly between years at 1 per cent with Pearson chi-squared test. ***Mean kgs planted by users also differ significantly at 1 per cent with two-tailed t-test.

Table 3. Comparison of means of outcome variables among smallholder maize farmers who grew and did not grow hybrid

	Plant hybrid			
	No	Yes	p-value	All maize growers
2002				
Income ('000 ZMK)	2,755	6,099	0.000	5041
Poverty severity	0.557	0.405	0.000	0.500
Total assets (ZMK)	1,781,518	4,734,044	0.000	2,885,744
Farm and processing equipment (ZMK)	173,339	813,843	0.000	412,883
Total livestock units (TLUs)	1.38	3.04	0.000	2.00
Relative deprivation (assets)	2,622,516	4,632,038	0.000	3,374,064
2006				
Income ('000)	3,067	10,205	0.000	6,109
Poverty severity	0.659	0.373	0.000	0.501
Total assets (ZMK)	2,144,122	8,610,570	0.000	4,900,018
Farm and processing equipment (ZMK)	173,206	1,077,290	0.000	558,512
Total livestock units (TLUs)	1.27	3.53	0.000	2.23
Relative deprivation (assets)	2,361,534	3,938,573	0.000	3,033,6425

Notes: N = 6,462. P-value refers to two-tailed difference of means test. The exchange rate was 4785.62 ZMK/USD during the 2002/03 agricultural season (Oct.–Sep.) and 4048.72 ZMK/USD during the 2006/07 season (Bank of Zambia).

vs 0.81 million ZMK). The mean number of livestock units owned by maize growers who did not plant hybrid seed was less than half that of maize growers who did. Mean relative deprivation with respect to total assets is significantly higher among hybrid seed users compared to other households in the SEA. Inspection of the data reveals that the dispersion of mean asset values of households ranked above any given household within the same SEA is greater among hybrid maize growers, even though the mean proportion represented by more highly ranked households is 0.20 as compared to 0.23 – a significant but not a meaningful difference between the two groups.[1]

3.2 Econometric Analysis

In this sub-section, we begin by summarising the results of preliminary diagnostic tests on the validity of the instrumental variable and potential endogeneity of hybrid seed use, followed by presentation and interpretation of results for the structural models.

As discussed above, the district level cumulative adoption rate is strongly partially correlated with the amount of hybrid seed planted by individual households. The reduced-form, CRE Tobit regression of hybrid seed planted on this variable and all of the exogenous regressors in Equation (3) suggests that a one percentage point increase in the cumulative adoption rate raises the amount of hybrid seed planted per farmer by an average of 0.07 kg (p=0.04, Online Appendix Table A2). The validity of district-level cumulative adoption as an instrumental variable is further supported by the fact that it is not statistically significant (p>0.10) when included as an additional regressors in the indicators of economic well-being regressions. This is the case for both the full sample and when restricted to only households that did not use hybrid maize. This falsification test is similar to the one used by Di Falco, Veronesi, & Yesuf, (2011) and provides support for the exclusion restriction for the instrumental variable from the main regressions.

Other coefficients in the reduced-form model of hybrid seed use are informative. As predicted by the conceptual approach of the farm household, distances to main and feeder roads, and to the nearest place to get vehicular transport, are negatively associated with the scale of hybrid seed planted by smallholder maize growers. A more educated household head has only a weakly positive effect on the amount of hybrid seed planted, reflecting that hybrid seed use is broadly distributed among the smallholder population and that years in school, in and of itself, is not a strong predictor of use. Farm size has a strongly significant effect on the kgs of hybrid seed planted. The magnitude of the regression coefficient is small in absolute terms (1.5 kgs per hectare owned, *ceteris paribus*), because not all of farm area owned is cropped and not all cropped area is planted to maize. Overall, human and farm capital factors are found to be significant, as in most studies of improved seed adoption.

Weeding wages are negatively associated with the amount of hybrid seed planted, reflecting the relative labour-intensity of recommended practices for managing hybrid seed and the scale of use. Fertiliser prices, on the other hand, are positively associated with hybrid seed use. This may suggest that the expected yield response of hybrid seed to fertiliser is greater than to local maize when moisture conditions are favourable, generating higher net returns at the margin even when fertiliser prices are high.

Including the generalised residuals from the reduced form CRE Tobit as an additional regressor in our indicators of economic well-being equations allows us to test the null hypothesis that hybrid seed use is exogenous against the alternative hypothesis that it is endogenous. Diagnostic tests are summarised in the Online Appendix (Table A3). We fail to reject the null hypothesis in all models. P-values on the coefficients are large, ranging from 0.637 to 0.928 for income and asset models. The p-value of the coefficient in the relative deprivation model is 0.136. However, the estimated coefficient is on kgs of hybrid seed planted is similar when the model is estimated with and without the residual from the first stage (–4,257 as compared to –4,583), and is significant at 11 per cent even when the residual is included. Thus, we report all regressions with hybrid seed use treated as an exogenous variable.

Having concluded that hybrid seed is exogenous to the indicators of economic well-being that we have measured (after controlling for the observed covariates and unobserved time invariant heterogeneity), we exclude the generalised residual in the final outcome regressions. This finding is not surprising given: (a) that we control for many important determinants of hybrid seed use and time invariant unobserved heterogeneity in the outcome regressions; (b) the diversification of income sources among maize-growing smallholders in Zambia; and (c) and the indirect linkages between maize seed use and the outcomes we consider.

Tables 4–6 show the regression results predicting the associations between hybrid seed use and the indicators of economic well-being. The FE model suggests that each kg of hybrid seed planted is associated

Table 4. Structural model, relationship of hybrid seed with on income and poverty severity

Explanatory variable	Income	Poverty severity
kgs hybrid	32.23***	–0.00172***
	(10.33)	(0.000458)
Distance to district town		–2.79e–05
		(0.000290)
Distance to tarmac road		0.000178
		(0.000143)
Distance to feeder road		–0.00328*
		(0.00187)
Distance to transport	–12.45	–0.000376
	(12.69)	(0.000598)
Female household head	–785.2	0.0117
	(569.6)	(0.0262)
Education of head	–19.58	–0.00774***
	(173.4)	(0.00232)
Maximum adult education	137.9*	–0.00242
	(72.84)	(0.00220)
Adults 15–59	155.8	0.0318***
	(147.6)	(0.00407)
Farm size	449.0**	–0.0228***
	(204.4)	(0.00597)
Crop concentration	1,374	–0.0427
	(1,729)	(0.0686)
Non-farm earnings	0.00122**	–8.12e–09
	(0.000606)	(9.05e–09)
Labour on other farms	0.000312	–3.47e–09
	(0.000984)	(2.27e–08)
Rainfall	–116.4	0.00613
	(94.20)	(0.00552)
Rainfall stress	208.4	–0.0173**
	(282.3)	(0.00747)
Expected rainfall	313.7	–0.00733
	(273.9)	(0.00983)
Rainfall cv	–57.18	–0.00229*
	(51.51)	(0.00119)
Maize price	721.2	–0.0680
	(1,491)	(0.0511)
Groundnut price	–5,103***	0.105*
	(1,704)	(0.0612)
Bean price	5,979**	–0.124
	(2,503)	(0.0826)
Sweet potato price	–74.84	–0.0227
	(994.5)	(0.0306)
Weeding wage	–2,805	–0.0525**
	(1,915)	(0.0218)
Fertiliser price	2,554	0.0436
	(2,913)	(0.0514)
2006	1,256	–3.041
	(1,764)	(2.751)
Number of observations	6,462	6,462

Notes: FE model for income ('000 ZMK); fractional response probit CRE model for poverty severity. Provinces and CRE coefficients not reported. Average partial effects (SE). *** p < 0.01; ** p < 0.05; * p < 0.1.

Table 5. Structural model, relationship of hybrid seed use with assets

Explanatory variables	Assets	Farm/Processing Equipment	TLUs
Kgs hybrid	29,245***	3,112***	0.00796***
	(5,824)	(669.7)	(0.00179)
Distance to district town	5,898	1,021	0.000792
	(3,773)	(696.6)	(0.00267)
Distance to tarmac road	–1,249	–84.82	–0.00648***
	(1,752)	(432.8)	(0.00182)
Distance to feeder road	59,416**	6,483	0.0161
	(25,535)	(5,123)	(0.0179)
Distance to transport	–1,910	58.18	0.00232
	(7,200)	(1,780)	(0.00543)
Female household head	–1.033e+06***	–297,702***	–0.409
	(377,852)	(114,351)	(0.290)
Education of head	81,111*	9,453	0.0361
	(42,847)	(8,163)	(0.0312)
Maximum adult education	–23,701	–2,164	–0.0261
	(46,480)	(9,714)	(0.0332)
Adults 15–59	162,718*	13,112	0.155**
	(95,427)	(14,345)	(0.0632)
Farm size	181,793	27,982**	0.0607
	(118,197)	(11,944)	(0.0448)
Crop concentration	–440,515	137,179	–0.384
	(1.065e+06)	(222,952)	(0.644)
Non-farm earnings	0.00716	0.0115	–1.55e–08
	(0.190)	(0.0340)	(1.06e–07)
Labour on other farms	0.487	0.166	1.86e–07
	(0.763)	(0.140)	(5.18e–07)
Rainfall	16,532	27,035**	0.0693*
	(47,736)	(10,953)	(0.0361)
Rainfall stress	–181,238**	–12,647	–0.138**
	(84,641)	(15,966)	(0.0639)
Expected rainfall	–78,133	–49,777*	–0.0194
	(100,963)	(26,924)	(0.0814)
Rainfall cv	–4,655	–3,488	–0.00393
	(17,997)	(3,401)	(0.0116)
Maize price	–677,025	40,569	0.0760
	(1.040e+06)	(112,227)	(0.612)
Groundnut price	–615,439	–202,322	–0.600
	(781,727)	(209,938)	(0.581)
Bean price	2.184e+06**	–96,079	1.282*
	(1.012e+06)	(276,976)	(0.716)
Sweet potato price	347,496	182,707*	0.749**
	(332,942)	(98,234)	(0.310)
Weeding wage	105,754	–51,617	0.134
	(460,769)	(76,161)	(0.290)
Fertiliser price	–180,017	20,598	0.0405
	(740,116)	(142,742)	(0.500)
2006	–211,224	38,915	0.0828
	(533,905)	(142,661)	(0.181)

Notes: Tobit CRE models. N = 6,462. Province and CRE coefficients not reported. Average partial effects (SE). *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$.

with a 32,230 ZMK (roughly 6,000 in current terms) increase in total household income on average. This is considerably more than the per kg price of hybrid seed in the capital city, Lusaka, which ranged from 4,300 to 12,000 ZMK during the study period. The CRE fractional response probit model (Table 4) predicts that each kg of hybrid seed planted by a smallholder maize-growing household is related to a 0.172 percentage point reduction in the severity of poverty. Farm land owned and the education of the household head are also significantly correlated with lower poverty severity. However, the number of prime-age adults is positively associated with the severity of poverty, perhaps reflecting the burden of additional household members in this age group on the food budget, school fees, and other consumption needs.

The CRE Tobit model (Table 5) confirms the strongly significant, positive correlation between hybrid seed planted and the values of total assets, farm and processing equipment, and the total number of livestock units owned. Each kg of hybrid seed planted by a smallholder maize-growing household is associated with an average increase of 29,245 ZMK (about 7 USD) in total asset values, and 3,112 ZMK (about 0.75 USD) in value of farm and processing equipment, including ox carts. The number of TLUs (cattle, sheep and goals, pigs, donkeys) is augmented by 0.008. (Recall that cattle, for example, have a TLU of 0.5.) The significance of other regression coefficients is similar across the asset equations, but not entirely. The negative effect of female headship is visible in the value of assets equations, but not TLUs. Education of the head is of importance in explaining variation in the total value of assets only. The availability of prime-age adult labour in the household is positively correlated with the total value of assets and numbers of livestock owned, but landholding size appears to be a significant predictor only in the asset model that explains the value of farm and processing equipment. Higher rainfall explains higher average values of farm and processing equipment and numbers of livestock owned by the household, while rainfall stress is associated negatively with total asset values and livestock units.

An increase in the amount of hybrid seed planted is associated with lower relative deprivation of smallholder maize-growing households within their SEA, as measured in terms of the value of total assets (Table 6). Human capital variables, including education of the head and numbers of prime-age adults, are also negatively associated with relative deprivation in terms of assets. Farm size also offsets relative deprivation. Rainfall variables also appear to have a strong association with relative deprivation, perhaps reflecting the location of the household. For example, rainfall stress bears a positive relationship with relative deprivation, the coefficient of variation is negatively associated with relative deprivation.[2]

4. Conclusions

Zambian smallholder farmers have been exposed to improved maize seed since before independence, when some of the early successes of maize breeding in Southern Africa (for example, SR52) were diffused among commercial farmers. Many of these early materials may have also diffused through the smallholder farmers and farm labourers who worked on and alongside these farms. It was not until the 1970s, however, when the strong commitment of the Government of Zambia to food security led to maize research focused on smallholder needs, and to the elaboration of an integrated input and output marketing scheme to support it. Since that time, the support of the GoZ, combined with the involvement of the private sector, has underpinned what has come to be known as Zambia's 'success story' in maize research and development among nations in sub-Saharan Africa.

Though a number of insightful, in-depth case studies have analysed the adoption of hybrid seed and its determinants in Zambia and in other maize-reliant countries in Africa south of the Sahara, a contribution of this study is to exploit Zambia's statistically representative, national database in order to measure quantitative associations with indicators of economic well-being. Our analysis focuses on the relationship between hybrid seed use and indicators of well-being beyond maize yields and profits. We use a two-year, balanced panel with 6,462 observations (3,231 households).

We view seed choices and economic well-being from the perspective of the non-separable model of the household farm, in which household and market characteristics, and particularly capital endowments and transactions costs, affect seed choice. Over time, if the use of hybrid seed is profitable, net returns may not only dampen the severity of poverty in any given year, but also contribute to the accumulation of productive assets.

Table 6. Structural model, relationship of hybrid seed use with relative deprivation

Explanatory variables	Relative deprivation (assets)
Kgs hybrid	–4,582***
	(1,719)
Distance to transport	–336.4
	(990.4)
Female household head	85,966
	(52,556)
Education of head	–12,397*
	(6,670)
Maximum adult education	17,496**
	(6,930)
Adults 15–59	–40,914**
	(17,122)
Farm size	–40,485*
	(20,707)
Crop concentration	–16,679
	(203,213)
Non-farm earnings	–0.0141
	(0.0324)
Labour on other farms	–0.103
	(0.121)
Rainfall	10,943
	(10,838)
Rainfall stress	27,629*
	(16,291)
Expected rainfall	11,659
	(26,421)
Rainfall cv	–7,343***
	(2,716)
Maize price	369,650**
	(160,785)
Groundnut price	247,973**
	(119,816)
Bean price	–970,035***
	(189,442)
Sweet potato price	–81,940*
	(43,735)
Weeding wage	64,629
	(83,231)
Fertiliser price	–139,027
	(125,732)
2006	239,465***
	(76,367)
Constant	–1.243e+07***
	(1.687e+06)

Notes: Huber–White heteroskedasticity and serial correlation robust standard errors in parentheses. FE model. N = 6,462. Province coefficients not reported. *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$.

We examine six indicators of economic well-being: (1) total household income; (2) the severity of poverty; (3) the value of all household and farm productive assets; (4) the value of farm and processing equipment – a subset of (3); (5) the total number of livestock units owned; and (6) relative deprivation with respect to the value of all assets. Based on an extensive empirical literature about the adoption of agricultural innovations in developing economies, we hypothesise that hybrid seed users may be 'better off' even prior to a decision to use hybrid seed; that is, we may observe a bias in the effects of hybrid seed use on any of these indicators due to self-selection.

To measure relationships between hybrid seed use and economic well-being, and given the structure of the dependent variables, we estimate CRE Tobit, CRE fractional response probit, and FE models after testing for the endogeneity of hybrid seed use. In all structural regressions, we fail to reject exogeneity of the amount of hybrid seed planted in outcome variables. We are not surprised by this result, given that many other factors influence economic well-being among Zambia's heterogeneous population of smallholder maize growers.

We find that among smallholder maize growers, each kg of hybrid seed planted in the survey years was associated with total household income that is 32,230 ZMK higher in nominal terms and severity of poverty that is 0.17 percentage points lower, on average. At the mean, controlling for other factors, each kg of hybrid seed planted was associated with 29,245 ZMK more in the value of total productive assets owned by maize growers. Thus, the 'long-term effect' (as expressed in the value of assets) was only slightly lower than the 'short-term effect' (as expressed in annual income). Similarly, an increase in hybrid seed use is positively correlated with the value of farm and processing equipment and the number of livestock units owned. Planting hybrid seed is associated with lower relative deprivation of maize-growing households compared to other similar households in the same SEAs.

Our findings underscore a fundamental point for Zambian policy. Maize growers who do not grow hybrids are strongly disadvantaged relative to those who do. Our regression results confirm what our descriptive statistics suggested – users and non-users of hybrids are distinct populations. Differences between them are pervasive, since hybrid seed use is associated with less severe poverty, as well as a larger asset base and wealth stored in the form of livestock and machinery. Although this finding appears to follow from a long history of hybrid seed use and preferential access to related resources by hybrid users, the heterogeneity of smallholder maize growers in Zambia suggested the need to test the hypothesis as rigorously as possible.

Further research is needed to assess possible changes over time and test the robustness of these results using other methods. At the time these data were collected, adoption rates remained relatively low (36.8%), although more recent estimates attain 58.4 per cent for F1 hybrid seed alone, with another nearly 20 per cent of farmers growing improved open-pollinated varieties and unidentified or recycled improved seed. Overall, both the revealed demand for improved maize seed and the estimates presented here attest to the positive effects of rising adoption rates among smallholder farmers in Zambia.

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Notes

1. The outcome variables have differentiated economic interpretation (current income as compared to longer-term income, all productive assets as compared to only farm and livestock assets, and relative deprivation with respect to other households in the SEA). Nonetheless, the matrix of partial correlation coefficients indicates significant correlations between assets and current income. Among them, relative deprivation is the least significantly correlated, with p-values of 0.06 in 2002 and only 0.37 in 2006.
2. Marginal effects are robust when estimated with pooled regressions rather than using FE or CRE models. All coefficients remain statistically significant at less than 1 per cent, and magnitudes are: 63.16 (income); –0.00180 (poverty severity); 32,474 (assets); 3,551 (farm and processing equipment); 0.00987 (TLUs). Only the magnitude of the income coefficient differs substantially.

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