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ABSTRACT

Zambian farmers have extensive experience with maize hybrids and input subsidies. Like other countries in Eastern and Southern Africa, the successful development and diffusion of improved maize seed in Zambia during the 1970s and 1980s was supported by strong government commitment to parastatal grain and seed marketing and subsidized provision of services to maize growers. When this system was dismantled under fiscal duress, production of the nation's staple food—maize—declined sharply. In 2002, concerned that national food security might be jeopardized, the government reinstated subsidies for fertilizers and maize seed through the Farmer Input Support Program (FISP), which had the stated goal of building the resource base of smallholder farmers. This analysis explores smallholder demand for hybrid maize seed by subsidy receipt. We test the hypothesis that the hybrid maize subsidy in Zambia is selectively biased due in part to its delivery mechanism and the self-selection of farmers who are able or choose to exercise their claim. Our analysis found that farmers with a lower poverty headcount are more likely to receive subsidized seed. In addition, a segment of farmers with a high predicted demand for hybrid seed are not reached by FISP—and they are poorer in terms of land and income than those who obtain the subsidy. These farmers represent a potentially important demand segment for HarvestPlus, which might consider addressing their needs through means other than a subsidy program.

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CONTENTS

I. INTRODUCTION

For major food staples such as maize, selling both improved seed and fertilizer at subsidized prices via state-owned companies was the modus operandi in many countries of Sub-Saharan Africa including Zambia, during the 1970s and 1980s. Bending under the fiscal burden of these systems and the pressure exerted by international financial institutions such as the International Monetary Fund (IMF), governments gradually dismantled them as part of structural adjustment programs launched in the 1980s and early 1990s. In recent years, policies seem to have come full circle, and subsidies are again commonplace, though they remain controversial (Kelly, Crawford, and Ricker-Gilbert 2011). Opponents point to the costly experiences of the 1970s and 1980s, arguing that subsidies undercut the private sector distribution network and divert scarce public funds from other important investments. Proponents believe that subsidies are needed to guide Africa's smallholder farmers toward commercialization and that the public use of funds is justified to reverse the secular trend of declining soil fertility (Minot and Benson 2009).

Zambia's smallholder farmers, who are widely dispersed across this relatively land-abundant but land-locked nation, have long depended on seed and fertilizer subsidies for maize production. Despite this dependence, Zambia's maize seed industry is one of the more dynamic in Eastern and Southern Africa with respect to diversity in types and numbers of seed companies (Kassie et al. forthcoming). Before independence in 1964, Zambian commercial farmers benefited from several highly successful hybrids produced by the maize breeding program in Southern Rhodesia. Following independence, donor investments in maize research led to the release of a plethora of improved open-pollinated varieties (OPVs) and hybrids that were adapted to the needs of smallholder farmers (Howard and Mungoma 1997).

In the 1980s the combination of suitable germplasm, fertilizer subsidies, pan-seasonal and pan-territorial pricing, and geographically dispersed market depots bolstered rates of return to maize production even in remote areas. After structural adjustment began in the 1990s, however, the area share of maize and the use of hybrid seed and fertilizer plummeted. Perceiving a threat to national food security with the decline of maize productivity, the Government of Zambia re-established subsidized inputs for maize production. The justification for the establishment of the Fertilizer Support Program (FSP) in 2002 was that a public role was needed to manage the transition toward full-market liberalization and to rebuild the resource base of smallholders.

Since 2002 fertilizer and maize seed have been distributed through the program, which operates by selecting private suppliers through a tender process. Local transporters distribute inputs to designated collection points, and selected cooperatives and other farmers' organizations issue inputs to approved farmers. To participate in the program, farmers must be members of registered farmers' organizations. Via their organizations, farmers pay a portion of the input costs at participating banks or financial institutions. Initially, the FSP package was designed for one hectare, supplying farmers with 200 kilograms (kg) each of basal and top dressing and 20 kg of hybrid seed. During the 2009/10 season, the size of the package was halved in order to facilitate diffusion to a wider range of smallholder farmers. The program is now known as the Farmer Input Support Program (FISP). The stated objectives of the program in 2012/13 were to a) expand markets for private sector input suppliers; b) ensure timely, effective, and adequate supply of improved agricultural inputs to targeted small-scale farmers; c) improve access of small-scale farmers to improved agricultural inputs; d) ensure competitiveness and transparency in the supply and distribution of inputs; e) serve as a risk-sharing mechanism for small-scale farmers; and f) facilitate the process of farmer organization and knowledge dissemination (Ministry of Agriculture and Livestock, GoZ, 2012).

In a number of countries scattered across Sub-Saharan Africa, empirical evidence is emerging that subsidies are often received by farmers who might otherwise purchase inputs commercially, undermining efforts to privatize seed and fertilizer industries (Xu et al. 2009; Ricker-Gilbert, Jayne, and Chirwa 2011; Mason and Ricker-Gilbert 2012). In effect, the government remains the major client of the seed industry, and farmers who purchase inputs can utilize the package to expand the scale of their use or trade their claims in secondary markets (Minot and Benson 2009; Holden and Lunduka 2010a, 2010b). Meanwhile, the goal of reaching poorer farmers is overshadowed by evidence that programs have promoted political patronage and the interests of rural elites (Banful 2010; Pan and Christiaensen 2012; Mason and Ricker-Gilbert 2012). Targeting programs could be made more efficient (Houssou and Zeller 2011). Based on farm panel data over a six-year period, Ricker-Gilbert and Jayne (2011) found that the receipt of the subsidy had little enduring effect on household income or asset wealth of recipients in Malawi.

In Zambia the case study implemented by the Civil Society for Poverty Reduction (CSPR 2005) found that FSP had very little impact on poverty or household food security. The World Bank's 2010 evaluation concluded that although the program had an impact on total fertilizer use and appeared justified for households that were food insecure, many farmers did not receive the amounts they expected (either more or less), most inputs arrived late, and beneficiary selection criteria "were too loose" to meaningfully target households or regions (World Bank 2010). Based on panel data collected by the Food Security Research Project and the Zambian Central Statistical Office in 2004 and 2008, Burke, Jayne, and Sitko (2012) found that the current subsidy program, FISP, tends to reach the least poor of smallholder farm households in Zambia. The third (32 percent) of smallholder farm households with less than 1 hectare (ha) of land received less than 10 percent of FISP fertilizer, while the third (37 percent) with over 2 ha received two-thirds of FISP fertilizers. Informal interviews conducted by the same authors suggest that smallholders who were unable to afford the co-payment sold their claim to larger farmers.

We hypothesize that there are two types of "selection bias" in FISP implementation in Zambia. First, the FISP packet is delivered to farmers who are members of registered cooperatives. Thus, qualifying farmers match the characteristics required by the formal and informal norms of their local cooperatives. Second, farmers who choose to exercise their claim to the package have more resources to do so. In 2012, for example, each farmer paid a total of ZMK280,000 (roughly US$54) for the FISP package purchased through registered cooperatives.

Our objectives in this paper are to a) test this hypothesis and b) explore potential hybrid demand segments for vitamin A-rich maize in the presence of the seed subsidy program. First, we test the hypothesis that the hybrid maize subsidy in Zambia is selectively biased due in part to its delivery mechanism and the self-selection of farmers who are able or who choose to exercise their claim. We apply an instrumented control function approach to single-period, cross-sectional data collected in 2011 from a sample of over 1,128 households in the major maize-producing provinces of the country. Second, we examine four groups of smallholder maize growers based on if they received a maize seed subsidy and if our model predicts they have a high demand for hybrid seed. Characteristics are compared statistically among groups in order to "profile" farmers and how they might be reached by information sources.

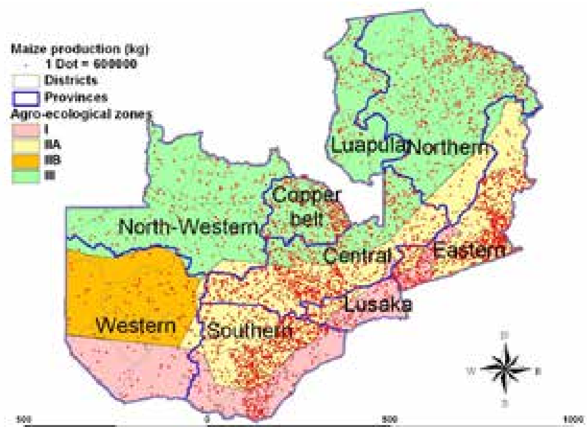
In designing a strategy to diffuse vitamin A-rich maize in Zambia, we perceive that HarvestPlus has two options to consider. The first would be to distribute the seed through FISP, which is the option being planned. A second option would be to distribute it through additional means, reaching growers who have a demand for hybrids that is not met through the subsidy program. Both might be pursued in order to attain maximum coverage.

2. DATA

The data were collected via face-to-face interviews in a farmer survey that was implemented by HarvestPlus, the International Maize and Wheat Improvement Center (CIMMYT), and the University of Zambia. A detailed description of the stratified, two-stage sample design is found in De Groote et al. (2012). The population domain included five provinces (Central, Copperbelt, Eastern, Lusaka, Northern, and Southern), located in three agroecological zones (I, IIA, and III) of Zambia.

The three agroecological zones (AEZs) served as strata. The total number of households in the sample was allocated proportionate to population and maize production (20 percent for zone I, 40 percent each for the other two zones). First-stage sampling units were standard enumeration areas (SEA), which totaled 113 and were selected with probability proportionate to size, by AEZ, from lists maintained by the Central Statistical Office. The second-stage units were households living in each SEA. In each SEA ten households were randomly selected from a list of all households. By design, data are self-weighted. Data were collected by three survey teams, each comprised of a supervisor and five enumerators, from June to August 2011. The full sample consists of 1,128 households, of which only 19 cultivated more than 20 ha. In Zambia farmers cultivating less than 20 ha are defined as "smallholders." Figure 1 shows the spatial distribution of maize production in Zambia, highlighting both its widespread nature and its concentration in Central, Eastern, and Southern provinces.

Figure 1: Distribution of Maize Production in Zambia



Source: Hugo De Groote, 2011

3. DESCRIPTIVE ANALYSIS

Because many farmers in Zambia have grown or been exposed to maize hybrids for years, we define hybrid users as growers of first-generation (F1) hybrids whose names they know. Farmers growing recycled hybrids, seed of hybrids they could not identify, or improved OPVs were not classified as hybrid users. During the 2010/11 rainy season, over two-thirds of farmers surveyed (68 percent) grew F1 hybrids that they could name. Over one-third of farmers grew local maize, but many of these were farmers who also grew F1 hybrids, recycled hybrids, improved OPVs, or a modern variety they could not name.

An estimated 65 percent of interviewed farmers received a maize seed subsidy, and virtually all of these (over 96 percent) cited FISP as the source. The remaining 4 percent of farmers cited the Programme Against Malnutrition (PAM), nongovernmental organizations (NGOs), or community development programs as sources. Three-quarters of farmers in AEZ III received the FISP subsidy, followed by 61 percent in AEZ IIA and 56 percent in AEZ I (Table 1). Thus, the chances of receiving a subsidy rise sharply from south to north.

Table 1: Percentage of Households Receiving Maize Seed Subsidy, by Agroecological Zone

		Received Subsidy		
		No	Yes	All
AEZ I	N	100	128	228
	%	43.9	56.1	100
AEZ IIA	N	174	276	450
	%	38.7	61.3	100
AEZ III	N	106	315	421
	%	25.2	74.8	100

Pearson chi-squared test indicates differences among zones significant at p=0.0000.
*p-value from difference-of-means tests conducted with two tails.
Source: Authors, based on data from HarvestPlus Maize Seed Adoption Survey, Zambia, 2011

On average across all zones, subsidy beneficiaries planted a total of 23 kg of seed, of which 18 kg were received from the subsidy program, implying that they purchased an additional 5 kg on their own—and that they also planted more than the standard FISP package. Farmers who did not benefit from the subsidy planted an

Table 2: Comparison of Mean (S.E.) Kilograms of Maize Hybrid Seed Planted, by Receipt of Maize Seed Subsidy and Agroecological Zone

	Received subsidy		
	No	Yes	p-value*
AEZ I			
Total hybrid seed (kg) planted	11.95	27.17	0.0025
	(3.336)	(3.539)	
Subsidized hybrid seed received	0.0	14.49	0.0000
	(0.000)	(0.923)	
AEZ IIA			
Total hybrid seed (kg) planted	8.98	20.85	0.0032
	(1.919)	(2.945)	
Subsidized hybrid seed received	0.0	18.63	0.0000
	(0.000)	(1.447)	
AEZ III			
Total hybrid seed (kg) planted	11.32	22.96	0.0023
	(2.729)	(1.995)	
Subsidized hybrid seed received	0.0	17.94	0.0000
	(0.000)	(1.125)	
All zones			
Total hybrid seed (kgs) planted	10.42	22.89	0.0000
	(1.45)	(1.56)	
Subsidized hybrid seed received	0.00	18.18	0.0000
	(0.000)	(0.754)	

*p-value from difference-of-means tests conducted with two tails.
Source: Authors, based on data from HarvestPlus Maize Seed Adoption Survey, Zambia, 2011

Table 3: Comparison of Mean (S.E.) Income, Assets, and Land by Receipt of Maize Seed Subsidy and Agroecological Zone

	Received subsidy		
	No	Yes	p-value*
AEZ I			
Total annual expenditures (millions ZMK)	7.45	10.71	0.1180
	(1.392)	(2.175)	
Total value of assets (millions ZMK)	82.84	55.84	0.7176
	(46.141)	(20.377)	
Total land+ (ha)	5.57	8.49	0.0118
	(0.798)	(0.961)	
Cultivated land (ha) in rainy season	2.17	3.62	0.0001
	(0.171)	(0.181)	
AEZ IIA			
Total annual expenditures (millions ZMK)	5.91	8.41	0.0302
	(0.838)	(0.908)	
Total value of assets (millions ZMK)	37.91	90.08	0.0981
	(7.95)	(31.47)	
Total land+ (ha)	14.44	11.67	0.3538
	(8.877)	(2.25)	
Cultivated land (ha) in rainy season	1.64	2.81	0.0001
	(0.219)	(0.215)	
AEZ III			
Total annual expenditures (millions ZMK)	11.01	9.79	0.2637
	(2.573)	(0.704)	
Total value of assets (millions ZMK)	52.47	55.01	0.4222
	(12.969)	(6.111)	
Total land+ (ha)	7.07	17.49	0.0789
	(1.183)	(4.252)	
Cultivated land (ha) in rainy season	1.68	2.48	0.0003
	(0.171)	(0.123)	
All zones			
Total annual expenditures (millions ZMK)	7.75	9.42	0.0569
	(0.900)	(0.604)	
Total value of assets (millions ZMK)	53. 88	68.59	0.2329
	(13.23)	(12.86)	
Total land+ (ha)	8.95	14.38	0.0909
	(2.859)	(2.471)	
Cultivated land (ha) in rainy season	1.89	2.97	0.0000
	(0.11)	(0.09)	

*p-value from difference-of-means tests.
+ Response rates were not as high for total land owned as for cultivated land in the rainy season, and we interpreted this variable as total land area to which farm households had access. Very little land was titled (overall mean of only 1.85 ha).
Source: Authors, based on data from HarvestPlus Maize Seed Adoption Survey, Zambia, 2011

average of only 10 kg of seed, less than half the amount planted by beneficiaries. This pattern holds when AEZs are taken individually (Table 2).

Following the maintained hypothesis of Burke, Jayne, and Sitko (2012), we found that across all three agroecological zones farm households who received the subsidy had significantly more income (proxied here by expenditures), total land, and cultivated land (Table 3). Given the variation in total assets, mean differences between beneficiaries and non-beneficiaries were not statistically significant. These differences were not consistent within zones, however. In AEZ I only landholdings differed significantly. Income, assets, and cultivated land differed in AEZ IIA but not total landholdings. In AEZ III only landholdings differed. Comparison of overall cumulative distributions shows that subsidy recipients dominated non-recipients with respect to land in the first-order, stochastic sense. Thus, the most salient finding is the difference with respect to either cultivated land or total land owned, or both. As both Burke et al. (2012) and Mason and Ricker-Gilbert (2012) found, FISP tends to favor those with more land. Based on these bivariate statistics, we conclude that subsidy delivery during the survey year was biased away from relatively resource-poor smallholders.

4. ECONOMETRIC STRATEGY

4.1 Conceptual Basis

We based the econometric specification on the theory of the agricultural household (Singh, Squire, and Strauss 1986), in which prices faced by the household are endogenous functions of the observed prices and the household characteristics that affect access to transaction information, credit, transport, and other market services. Seed demand is conditioned on agroecologies, which affect agronomic performance and trait preferences. Seed supply and demand are influenced by seed subsidy and seed prices. The general form of the estimated equation can be represented by

$$H = h(s, P_h, P_m, \Omega_h, \gamma, \lambda). \qquad (1)$$

H is quantity of hybrid seed planted by the household, s records whether or not the household receives hybrid seed via a subsidy, P_h is the seed price paid at the farm-gate, and P_m is the market price for maize grain. The vector Ω_h includes household characteristics, and γ is an indicator of the agroecological conditions in which the household farms. The variable λ refers to trait preferences, which are parameters of the underlying utility function of the household theoretic framework.

4.2 Estimation Procedure

The cross-tabulations presented above suggest that maize seed subsidy (s) may be endogenous in the decision to grow hybrid seed. In cross-sectional data of the type used in this analysis, an explanatory variable is endogenous as a consequence of omitted variables, simultaneity, measurement error, or sample selection bias. A body of literature has been devoted to using instrumental variables to reduce bias from omitted variables in the estimate of causal relationships; this method allows us to estimate the coefficients of interest consistently and without asymptotic bias. As explained by Angrist and Krueger (2001), instrumental variables solve the omitted variables problem by using only part of the variability in the explanatory variable—the part that is uncorrelated with omitted variables—to estimate the relationship between the dependent and explanatory variables. The instrumental variables approach has also been extensively applied in order to handle selection bias in studies of targeted and voluntary participation in programs and their impacts (Ravallion 2005). Referencing earlier work by Imbens and Angrist (1994), Angrist and Krueger (2001) note that with a dummy endogenous regressor, instrumental variables techniques estimate causal effects for those who would "take the treatment" (grow hybrid seed) only when assigned to the treatment group (a subsidy program).

The general form of equation 1, rewritten as an instrumental variables model, is

$$s_i = x_{1i}\Theta_1 + x_{2i}\Theta_2 + v_i \qquad (2)$$

$$h_i = x_{1i}\beta_1 + s_i\beta_2 + \mu_i \qquad (3)$$

where the dependent variables include s, which measures subsidy receipt, and h, which measures the impacts of the subsidy on hybrid seed use. The vector x_1 represents a set of explanatory variables that influence both subsidy receipt and hybrid seed use, and the vector x_2 includes instrumental variables that explain hybrid seed use only. The error terms of the equations, v and μ, have means of zero but are potentially correlated.

The model is estimated using two-stage least squares with a binary variable measuring maize seed subsidy receipt as a dependent variable in the first stage. Angrist and Krueger (2001) state that even in the case of a dichotomous variable in the first of the two equations, two-stage least squares produces consistent estimators that are less sensitive to assumptions about functional form. They advocate this approach over using nonlinear models such as probit or logit in two-stage least squares regression. If we fail to reject the hypothesis of endogeneity, we apply two-stage least squares; if we reject it, we estimate the equation (3) with a single regression.

Our equation system has an additional constraint: the demand for hybrid seed includes a corner solution response for farmers whose optimal choice is zero. Tobit regression can be used to estimate demand including zero values but not with instrumental variables estimated with two-stage least squares (Wooldridge 2002). The control function approach enables us to account and test the endogeneity or self-selection bias in a nonlinear model such as the Tobit when the suspected endogenous variable is binary.

Like the procedure we describe above, the control function approach requires an instrumental variable to be used in the first-stage, reduced-form estimation of seed subsidy receipt. The instrumental variable should be correlated with receipt of the seed subsidy in the first stage-regression but should not be correlated with the amount of hybrid seed planted in the second-stage regression, except through the effects of the seed subsidy. In the second stage, however, the structural model is estimated with the observed endogenous variable and the residual from the first stage included as explanatory variables. The test of endogeneity is the statistical significance of the coefficient of the residual, with bootstrapped standard errors. The control function approach, described in early work by Smith and Blundell (1986) and Wooldridge (2002), has been applied by Ricker-Gilbert, Jayne, and Chirwa (2011) to model the effects of the fertilizer subsidy in Malawi and Mason and Ricker-Gilbert (2012) to model seed subsidy effects in Zambia and Malawi, using fixed effects regression with panel data.

We use a single period cross-section. In the first-stage regression, we regress the binary maize seed subsidy variable against all exogenous variables in reduced form. Membership in the registered association, which affects hybrid seed use only via rights to the subsidy, served as the instrumental variable. In this regression, given the systematic relationship hypothesized between the seed price (unit value of expenditures on maize seed) and the maize seed subsidy, we used distance to the source of seed for the major maize variety as an indicator of household transactions costs. We estimated two second-stage regressions, testing the endogeneity of the maize seed subsidy by including the residual estimated from the first-stage regression. Self-selection bias could be expressed through the decision of some farmers, and not others, to exercise their claim. It might also be expressed by some farmers who have no claim because they are not members of registered associations but who are able to purchase additional seed from those who receive the subsidy. In the first second-stage regression, the dependent variable was a binary variable indicating whether or not the farm household grew hybrid maize. We also estimated a Tobit regression with the amount of hybrid seed planted as the dependent variable. All regressions were estimated with fully robust standard errors, accounting for possible clustering by village in the sample design.

To analyze characteristics of demand segments, we used the predicted values of the second-stage, probit regression to group households according to predicted values above and below 90 percent. Since adoption of F1 hybrids in Zambia is high due to FISP, there are a large number of households with high probabilities of adoption.

4.3 Variable Definition

Definitions of variables we use to measure the parameters in equation (1) and their summary statistics are shown in Table 4. For household characteristics (Ω_h), we included the quality and quantity of human capital in terms of the number of literate persons in the household, the number of dependents, and the number of adults. We do not use *de facto* headship because it is not significant in maize seed subsidy receipt and is correlated with other observed and unobserved explanatory variables in the hybrid seed equations. Total land owned was used as a measure of physical capital. We sacrificed some observations because data were sparser for this variable than for land cultivated during the rainy season, which is a choice variable related closely to the quantity of hybrid seed planted. Previous research has also indicated that in much of rural Zambia, labor rather than land remains the primary production constraint, as expressed in the labor variables we included (Kimhi 2006). The amount of credit received was non-zero in only 21 cases and was not included as a separate indicator of financial capital.

Broadly speaking, the natural capital of the household is strongly influenced by the agroclimatic and farming conditions of the area. We improve on dummy variables for agroecological zones by using average temperatures and the range of temperatures keyed to georeferenced coordinates recorded for each household (γ). Temperatures are based on high-resolution monthly

1 The data layers were generated through interpolation of average monthly climate data from weather stations on a 30 arc-second resolution grid (often referred to as "1 km²" resolution). Included variables are monthly total precipitation, monthly mean, minimum and maximum temperature, and 19 derived bioclimatic variables (Kai Sonders, CIMMYT, personal communication).

climate data from 1950–2000 (Hijmans et al. 2005).[1]

As discussed in detail by Smale and Mason (2012), factor scores computed with principal components were used to express seed preferences in the baseline survey from this study. Farmers were asked to rank the importance of agronomic traits (emergence, plant vigor, resistance to drought, resistance to field pests, resistance to storage pests, resistance to plant diseases, early maturity, yield), cob and grain qualities (cob size, good tip cover, grain color, grain weight), processing and cooking attributes (water absorption capacity, pounding ability, taste as *nshima*, taste roasted), and market demand. Principal components with varimax rotation were applied to the 17 variables for the purpose of reducing the number of covariates measuring preferences.

Among the 17 variables, two factors explained roughly half of the variation, in roughly equal proportions. These were selected for factor score computation. The attributes that load most heavily (whose coefficients are largest) in the first factor are related to agronomic performance of maize seed. Those that load most heavily in the second are associated with grain processing and consumption. The two factors are called "importance of agronomic traits" and "importance of consumption traits" in Table 4. The third factor, which explains less, is dominated by grain color and demand. Eigen values were 8.37 and 1.25 for Factors 1 and 2 (for factor loadings, see Smale and Mason 2012).

Enumerators recorded seed costs and amount purchased by farmers, from which we have calculated a farm-gate seed price P_h (unit value). Output prices P_m were reported in only 421 cases (only 579 farmers sold any maize), and we did not include this variable. A noted above, we also use the distance to the source of the major maize variety grown by the household as an indicator of transactions costs.

To handle some of the unobserved heterogeneity among households using cross-sectional data, we also included fixed district effects but do not report these in the results tables.

Table 4: Variable Definition and Summary Statistics

Variable	Construction	Mean	St. Dev.
Dependent			
Hybrid seed planted	Total kg planted, named F1 hybrid	19.3	41.0
Explanatory variables			
Received seed subsidy (endogenous)	1=received maize seed subsidy; 0=otherwise	0.654	0.476
Literacy	Number of literate household members	3.66	2.35
Dependents	Number of household members <15 and >64 years of age	3.58	1.89
Active adults	Number of households >15 and <64 years of age	3.28	2.09
Land	Total land area owned by household	12.56	53.86
Importance of agronomic traits	Factor score (see Smale and Mason 2012)	-0.00304	0.989
Importance of consumption traits	Factor score (see Smale and Mason 2012)	-0.0229	1.006
Average temperature	Average mean monthly climate data "1 km2" resolution from 1950–2000	20.9	1.36
Temperature range	Average maximum less average minimum temperature at 1 km2 resolution from 1950–2000	13.4	1.20
Registered association	1=household member a member of a registered association; 0=otherwise	0.71	0.45
Distance to seed source	Km to seed source of major maize variety	17.01	43.86
Seed price (ZMK/kg)	Total maize seed expenditures/kg planted	8098.86	5790.39

Source: Authors, based on data from HarvestPlus Maize Seed Adoption Survey, Zambia, 2011

5. RESULTS

5.1. Regression Analysis

The first-stage, reduced form probit regression that predicts receipt of the maize seed subsidy is shown in Table 5. The higher the number of literate adults in the household, the more likely the household is to receive a subsidy. Literacy of household members clearly improves the chances that the household will have information regarding access and rules of subsidy receipt and payment, terms of the subsidy, and other information that links household members to productive resources. However, the number of dependents, number of adults, and land area are not statistically significant determinants of seed subsidy receipt. Stronger consumption preferences increase the likelihood of receiving the subsidy at the 6 percent significance level. This may reflect the preferences of more subsistence-oriented households reached by the subsidy or those of farm households in Eastern Province, where subsidy receipt was relatively higher than in AEZ I. A higher average temperature and wider range of temperatures results in a lower probability of receiving the subsidy. Higher temperatures, with a greater range, are found in the southern area of the country where the likelihood of subsidy receipt is lowest. Membership in a registered association, the instrumental variable, is strongly related to receipt of the seed subsidy, by a large magnitude and a negligible p-value (membership is not a perfect predictor because some members sell their claims to non-members, and not all members exercise their claims).

Holding these factors constant, households that are more remote with respect to the major maize seed source are less likely to be subsidy recipients. As we would expect, seed subsidy recipients are better “connected” to seed sources.

Regression of the binary variable for hybrid use on all exogenous variables with the exception of the instrumental variable entered in the first-stage regression results in failure to reject the null hypothesis that maize seed subsidy receipt is exogenous. The p-value of coefficient on the residual from the reduced form regression is 0.133. We also fail to reject the null hypothesis that the subsidy is exogenous in the decision of how much hybrid seed to plant, based on the Tobit regression that includes the residual from the first-stage regression (the p-value of the coefficient of the residual in the Tobit regression is 0.238). Thus, the criteria for subsidy receipt are not choice variables, at least as these are measured in a single season of data collection.

Table 6 shows the results of the probit regression predicting use of hybrid maize seed with the maize seed subsidy treated as an exogenous variable and the seed unit value entered in place of the transactions costs variable. Although we expect the price variable and seed subsidy variable to be systematically related, their partial correlation coefficient is only weakly significant, with a p-value of 0.11. Thus, for coherence between our conceptual model and economic theory, we control for the subsidy effect, as well as for seed expenditures per unit, in the equation explaining the probability that smallholder maize growers plant hybrid seed.

Table 5: First-stage, Reduced Form Probit Predicting Receipt of Maize Seed Subsidy

	dy/dx	Std. Err.	P>z
Literacy	0.0224	0.0066	0.0010
Dependents	-0.0012	0.0053	0.8200
Adults	-0.0094	0.0076	0.2180
Land area (ha)	0.0049	0.0059	0.4070
Agronomic preferences	-0.0154	0.0128	0.2280
Consumption preferences	0.0182	0.0097	0.0610
Average temperature	-0.0156	0.0091	0.0860
Range in temperatures	-0.0523	0.0108	0.0000
Registered association	0.3752	0.0184	0.0000
Distance to seed source	-0.0003	0.0001	0.0200

Wald $chi^2(20)$ = 277.59, Prob>chi-squared = 0.0000, n=725
Log pseudolikelihood = -197.75421
Note: District-fixed effects and constant not listed in table; dy/dx=average partial effects.
Source: Authors, based on data from HarvestPlus Maize Seed Adoption Survey, Zambia, 2011

Table 6: Probit Regression Predicting Decision to Grow Hybrid Maize

	Delta-method		
	dy/dx	Std. Err.	P>z
Literacy	0.0151	0.0111	0.1720
Dependents	0.0087	0.0080	0.2760
Adults	-0.0105	0.0131	0.4250
Land area (ha)	0.0001	0.0003	0.6890
Agronomic preferences	0.0211	0.0193	0.2760
Consumption preferences	-0.0513	0.0210	0.0150
Average temperature	-0.0215	0.0156	0.1690
Range in temperatures	-0.0106	0.0157	0.4970
Seed price	1.19E-065	3.38E-06	0.0000
Receive subsidy	0.1697	0.0359	0.0000

Wald $chi^2(20)$ = 72.35, Prob>chi-squared = 0.0000, n=727
Log pseudolikelihood = -272.5509
Note: District-fixed effects and constant not listed in table; dy/dx=average partial effects.
Source: Authors, based on data from HarvestPlus Maize Seed Adoption Survey, Zambia, 2011

Table 7: Tobit Regression Predicting Amount of Hybrid Maize Seed Planted

	Delta-method		
	dy/dx	Std. Err.	P>z
Literacy	3.0041	1.4721	0.0410
Dependents	-0.5336	0.7204	0.4590
Adults	-3.0677	1.7914	0.0870
Land area (ha)	11.6117	1.7369	0.0000
Agronomic preferences	2.8679	2.3079	0.2140
Consumption preferences	-6.7049	1.9926	0.0010
Average temperature	-1.2850	1.4121	0.3630
Range in temperature	2.6060	1.5933	0.1020
Seed price	0.0011	0.0004	0.0010
Receive subsidy	9.8327	3.6770	0.0070

F (20) = 8.48, Prob > F = 0.0000, n=727
Log pseudolikelihood = -2241.681 , Prob > chi2 = 0.0000
Note: District-fixed effects and constant not listed in table.
Source: Authors, based on data from HarvestPlus Maize Seed Adoption Survey, Zambia, 2011

Other factors held constant, farmers who express a strong preference for the consumption characteristics of varieties (typically for flint over dent types) are less likely to grow an F1 hybrid (see De Groote et al. 2012 for discussion of grain texture). The effect of the maize seed subsidy on the probability of growing a named F1 hybrid is powerful, raising it by 17 percentage points on average. The seed price is positively related because controlling for the effect of the subsidy, prices of F1 hybrids are higher than the prices of other types of seed. Other seed types purchased include recycled hybrids, improved OPVs, unnamed modern maize types, and occasionally local maize, for much lower prices and typically under duress (when farmers have no stocks of their own). As we have shown above, those who receive subsidies often also purchase non-subsidized F1 hybrid seed on the market.

Tobit regression results are shown in Table 7, and these are generally more robust because both the likelihood and scale of hybrid seed use are measured in the dependent variable. Results for the truncated regression are weak, and we favored the use of the Tobit over the double hurdle model for explanatory purposes. Receiving the subsidy increases the average amount of hybrid maize seed grown by 10 kg on average, which is the amount included in the package (equivalent to 0.5 hectare assuming the average seeding rate of 20 kg per ha). The seed price is related positively to the amount grown, for the same reasons cited above. On average, seed subsidy recipients planted 2.97 ha of maize compared with 1.39 ha planted by non-recipients in the survey season. Even considering the subsidy effect, an additional hectare per farm is associated with 12 more kg of hybrid seed. However, not all land is devoted to maize. Average temperature and the range of temperatures have no statistical relationship with hybrid use in the Tobit regression. The role of the seed price and maize seed subsidy both remain strong and positive, as in the probit regression.

5.2. Post-Estimation Analysis

The probit results (Table 6) are employed in this section to examine the structure of the demand for maize hybrids along two axes: 1) maize growers with a probability greater than 90 percent of planting hybrids and 2) maize growers who did and did not receive subsidized seed. We selected 90 percent although it is a large likelihood value because use rates and predicted use rates are quite high in Zambia. Otherwise, the choice of cutoff point was arbitrary and selected for the purposes of demonstrating an unmet demand and with an eye to subsample sizes. The percentage distribution of the resulting four groups is shown in Table 8.

Among the farmers who received subsidized seed (719 total) about 45 percent had a low probability of growing hybrids. Among those who did not receive subsidized seed (380 total), 61 percent had a high probability of growing hybrids. This percentage was evidently higher than the percentage of farmers who had a high probability of growing hybrids and also received subsidized seed. On the basis of these figures, we conclude that there is a potentially large (in terms of share of the population), "unsubsidized" demand for hybrid seed in Zambia.

In Tables 9 and 10 we explore poverty among subsidy recipients and farmers with a high probability of growing hybrids. Among the many possible indicators of poverty, we use the simplest form of the well-known Foster-Greer-Thorbecke index—the headcount ratio. The national poverty line calculation in Zambia has been criticized based on measurement issues and various types of bias in calculation (Chibuye 2011), so we used international poverty lines. We multiplied the World Bank poverty lines ($1.25 or $2.00 per capita per day) by the ratio of the Gross Domestic Product (GDP) measured in current ZMK to its equivalent expressed in terms of international dollars (converted by Purchasing Power Parity). For example, the ratio provides the number of ZMK required to purchase one international dollar in 2010. Per capita daily amounts were multiplied by 365 days and household size. We then compared reported annual income for each household during the year preceding the survey to the poverty line, coding those below the poverty line as 1 and those above as 0. A more exhaustive analysis would consider multiple indicators, or a multidimensional indicator (Alkire et al. 2011), but the focus of our study is maize-hybrid use rather than poverty per se.

Consistent with Burke, Jayne, and Sitko (2012) and Mason and Ricker-Gilbert (2012), we find that farm households that received the subsidy in 2010/11 have significantly lower headcount ratios (lower poverty rates) as a group than those who did not, whether measured at the ZMK international equivalent of $1.25 or $2.00 per capita per day (Table 9). We again conclude that the subsidy in the survey year was selectively biased toward less poor farm households. Considering only those households with a high probability of growing maize hybrids, FISP also includes a set of households with a lower headcount poverty ratio (Table 10).

Table 8: Number and Percent of Households with High Probability of Growing Maize Hybrid, by Receipt of Maize Seed Subsidy

		Pr > 90%		
Subsidy		No	Yes	All
No	N	148	232	380
	%	38.95	61.05	100
Yes	N	324.00	395.00	719
	%	45.06	54.94	100
All households	N	472	627	1099
	%	42.95	57.05	100

Note: Pearson chi-squared tests shows difference in distribution by subsidy receipt at p=0.051.
Source: Authors, based on data from HarvestPlus Maize Seed Adoption Survey, Zambia, 2011

Table 9: Headcount Poverty Ratio, All Households, by Receipt of Maize Seed Subsidy

	Received subsidy			
Poverty line	No	Yes	All	p-value*
$1.25/day (PPP)	0.8263	0.7677	0.7880	0.0240
$2/day (PPP)	0.9079	0.8679	0.8817	0.0510

*p-values from difference-of-means tests, n=1105.
Source: Authors, based on data from HarvestPlus Maize Seed Adoption Survey, Zambia, 2011

Table 10: Headcount Poverty Ratio, Households with High Probability of Growing Hybrid Maize, by Receipt of Maize Seed Subsidy

	Received subsidy			
Poverty line	No	Yes	All	p-value*
$1.25/day (PPP)	0.8707	0.7747	0.8102	0.0030
$2/day (PPP)	0.9181	0.8582	0.8804	0.0090

*p-values from difference-of-means tests, n=1105.
Source: Authors, based on data from HarvestPlus Maize Seed Adoption Survey, Zambia, 2011

Table 11: Percentage Distribution of Households with High Probability of Growing Hybrid Maize, by Receipt of Maize Seed Subsidy and Agroecological Zone

		I	IIA	III	Total
Subsidy	N	77	194	124	395
	%	19.49	49.11	31.39	100
No subsidy	N	54	125	53	232
	%	23.28	53.88	22.84	100
Total	N	131	319	177	627
	%	20.89	50.88	28.23	100

Pearson $chi^2(2) = 5.4357$, Pr = 0.066
Source: Authors, based on data from HarvestPlus Maize Seed Adoption Survey, Zambia, 2011

These findings suggest that not only is there a sizeable potential demand for maize hybrids not met by the subsidy program but that households in this demand segment also have a higher poverty rate. The distribution across agroecological zones of households that have a high probability of growing maize hybrids and do not receive the subsidy is significantly, but weakly (p-value=0.07), different from that of those who did receive the subsidy. Also, it is not evident that these differences are particularly meaningful in magnitude. The match between subsidy receipt and high probability of demand for hybrids appears closer in AEZ III than in the other AEZs (Table 11).

On a provincial basis, however, high demand farmers who did not receive subsidized seed were more often located in Copperbelt and Eastern Provinces and much less often found in Northern Province, with some slight differences in Lusaka. Differences in Central and Southern Provinces seem to be negligible (Table 12).

In the following tables, we explore the characteristics of farm families with high probability of growing maize hybrid who did and did not receive the subsidy and those who were "left out"—that is, they have a low probability of growing hybrids and did not receive the subsidy. Differences of means and percentages are reported only for the two groups with a high probability of growing hybrids.

In terms of farm household characteristics, high-probability hybrid growers who received the subsidy are no different from those who did not in terms of the share of female household heads, age of the household head, number of children from 1–3 years of age, and number of household members over 46 years of age (Table 13). However, high-probability hybrid growers who have

Table 12: Percentage Distribution of Households with High Probability of Growing Hybrid Maize, by Receipt of Maize Seed Subsidy and Province

		Central	Copperbelt	Eastern	Lusaka	Northern	Southern	Total
Subsidy	N	43	42	125	33	61	90	394
	%	10.91	10.66	31.73	8.38	15.48	22.84	100
No subsidy	N	25	31	96	14	16	50	232
	%	10.78	13.36	41.38	6.03	6.9	21.55	100
Total	N	68	73	221	47	77	140	626
	%	10.86	11.66	35.3	7.51	12.3	22.36	100

Pearson chi^2(5) = 14.6967, Pr = 0.012
Source: Authors, based on data from HarvestPlus Maize Seed Adoption Survey, Zambia, 2011

Table 13: Household Characteristics by Probability of Growing Hybrid Maize and Receipt of Maize Seed Subsidy

	Pr < 90 %	Pr > 90 %		
	No subsidy	No subsidy	Subsidy	p-value
Female head (%)	15.17	23.38	20.92	0.5147
Age of head (yrs)	47.76	49.00	49.02	0.9877
Household members 1 to 3 yrs	0.51	0.66	0.64	0.7212
4 to 8 yrs	1.01	1.02	1.25	0.0131
9 to 13 yrs	0.96	0.91	1.33	0.0000
14 to 18 yrs	0.93	0.91	1.21	0.0013
19 to 45 yrs	2.07	1.91	2.22	0.0034
46 + yrs	0.81	0.88	1.00	0.1262
Household size	6.29	6.29	7.66	0.0000
Residence in village (yrs)	18.21	20.21	22.93	0.0000
Number of literate adults in household	3.07	2.83	4.24	0.0000
Seed decisionmaker male (%)	80.69	68.40	77.16	0.0160
Seed decisionmaker literate (%)	75.86	66.67	82.74	0.0000
Seed decisionmaker age (yrs)	47.21	47.32	47.91	0.6291
Cultivated land area (ha)	1.59	2.08	3.33	0.4135
Total land area (ha)	5.81	12.94	20.66	0.0000
Assets (millions ZMK)	67.71	44.98	80.09	0.2375
Income (millions ZMK per year)	9.23	6.79	10.08	0.0189
Member of registered farmer association	26.35	22.94	93.64	0.0000
Estimated maize surplus+	974.56	978.05	3297.35	0.0000
Sold maize (%)	24.14	27.03	69.33	0.0000
Attended a variety demonstration (%)	5.41	6.03	36.96	0.0000
Owns a cell phone (%)	58.11	48.26	78.17	0.0000
Owns a radio (%)	68.92	64.78	83.50	0.0000
Owns a television (%)	31.39	20.77	45.61	0.0000
Has heard of vitamin A (male respondent %)	75.56	78.40	84.07	0.1380
Has heard of vitamin A (female respondent %)	87.50	80.70	87.86	0.0334

*p-value from difference-of-means tests or Pearson chi-squared tests for percentages
+ Estimated total production less total consumption
Differences tests between high probability groups only
Source: Authors, based on data from HarvestPlus Maize Seed Adoption Survey, Zambia, 2011

received the subsidy have more children and adults in other age groups (4–8, 9–13, 14–18, 19–45 years), and their household size is larger on average by one person. These households have also lived longer in the village and have more literate adults. The proportion of seed decisionmakers who are men is higher in the subsidized group, and the proportion of seed decisionmakers who are literate is considerably greater (77 percent compared with 68 percent). Total land area (but not cultivated land area) and income are higher for the subsidized growers than for the unsubsidized ones. While the total value of assets did not differ between the three groups, the share of households owning cell phones, radios, and televisions was greater among subsidy beneficiaries. As expected, almost all of subsidy beneficiaries belonged to a registered farmer association, compared with only 23 percent of high-probability hybrid growers who did not receive a subsidy. This statistic also suggests that some members of farmer associations did not choose to exercise their right to purchase subsidized seed. A much higher proportion of farmers with a high probability of growing hybrids who received a subsidy had attended a variety demonstration. Although there was no difference among male respondents, female respondents in the group of high-probability growers were more likely than others to have heard of vitamin A. This may reflect literacy or proximity or access to health clinics (Table 13).

Compared with the groups with a high probability of growing maize hybrids, the group of farmers with a low probability of growing hybrids who did not receive a subsidy appears to have a much lower proportion of female-headed households and slightly younger household heads. Notably, they have resided in the surveyed village for the least number of years among all groups. However, these farmers are similar to the high-probability hybrid maize growers who did not receive subsidy in terms of the age-group distribution of members and overall household size. Their seed decisionmakers are also the same age as those of the other groups, with literacy rates between the two, and the highest percentage who are men. Their land sizes are only a fraction of those of the other groups, but their income and assets are comparable. Their membership in registered farmer associations and attendance at variety demonstrations are similar to that of the unsubsidized, high-probability growers. Male respondents in this group are the least familiar with vitamin A, but female respondents are as aware as those in the subsidized group (Table 13).

Of particular interest are the statistics related to maize sales and surplus maize production. Consistent with our other findings, farmers with a high probability of growing maize hybrids but who did not receive a subsidy were significantly less likely to sell maize, and we estimate that the maize surplus (production over consumption) that they produced was less than one-third that of high-probability hybrid growers who received the subsidy (Table 13).

To explore means by which maize growers might be reached, we also analyzed their sources of agricultural information. In general, male respondents and female respondents in the high-demand, subsidy-receiving group are more likely to use any type of information source than those in the other two groups. The difference is most pronounced with respect to using information provided by extension. The lower literacy of the high probability growers who did not receive a subsidy, relative to the other two groups, is evidenced by the fact that fewer of them read the newspaper, whether male or female (Table 14, Table 15).

The primary sources of seed are presented, by group, in Table 16. By far the largest source of seed for the low probability hybrid grower group not receiving the subsidy is the agrodealer, followed by family, neighbor, or own stocks. Farmers in this group clearly purchased improved seed from agrodealers and obtained recycled, improved seed or local maize from close contacts or the previous harvest. A small percentage reported obtaining seed via the subsidy or a farmer association—this would be through a secondary market, where farmers decide to sell some or all of their subsidized hybrid seed to other farmers. Among farmers who received the subsidy and have a high probability of growing hybrid seed, over half obtained their seed through the program. However, 24 percent also purchased seed from an agrodealer and 3 percent directly from a seed company. The group of farmers with a high probability of growing maize hybrids who did not receive a subsidy relied much more heavily on family, neighbors, and their own stocks than either of the other two groups, although 30 percent also purchased from agrodealers and another small percentage obtained seed indirectly from the subsidy program.

Table 14: Percentage of Male Respondents Using Information Source, by Probability of Growing Hybrid Maize and Receipt of Maize Seed Subsidy

		Pr < 90%	Pr > 90%		p-value*
		No subsidy	No subsidy	Subsidy	
Newspaper	N	28	23	92	0.000
	%	30.43	14.56	33.58	
Radio	N	74	130	244	0.003
	%	80.43	82.28	89.05	
Clinic	N	45	95	168	0.198
	%	49.45	60.13	62.22	
Extension	N	28	53	207	0.000
	%	30.43	33.54	75.82	
Social group	N	16	9	35	0.000
	%	17.98	6.04	14.06	

*p-value from Pearson chi-squared test
Source: Authors, based on data from HarvestPlus Maize Seed Adoption Survey, Zambia, 2011

Table 15: Percentage of Female Respondents Using Information Source, by Probability of Growing Hybrid Maize and Receipt of Maize Seed Subsidy

		Pr < 90%	Pr > 90%		p-value*
		No subsidy	No subsidy	Subsidy	
Newspaper	N	5	9	37	0.003
	%	10.38	5.36	12.01	
Radio	N	74	100	227	0.198
	%	70.48	59.17	73.94	
Clinic	N	75	139	263	0.008
	%	71.43	82.25	86.23	
Extension	N	16	20	165	0.000
	%	15.09	11.98	53.92	
Social group	N	17	15	41	0.000
	%	16.5	9.32	14.19	

*p-value from Pearson chi-squared test
Source: Authors, based on data from HarvestPlus Maize Seed Adoption Survey, Zambia, 2011

Table 16: Primary Source of Seed for Major Maize Variety, by Probability of Growing Hybrid Maize and Receipt of Maize Seed Subsidy

		Pr < 90%	Pr > 90%	
		No subsidy	No subsidy	Subsidy
Seed company	N	1	7	9
	%	0.69	3.17	2.52
Agrodealer	N	86	66	84
	%	59.31	29.86	23.53
Subsidy or farmer association	N	19	7	188
	%	8.28	3.16	52.66
Local or district market	N	7	7	14
	%	4.83	3.17	3.63
Family, neighbor, stocks	N	30	126	51
	%	20.69	57.01	14.29
Other	N	7	8	11
	%	5.52	3.62	3.08
All	N	150	221	357
	%	100	100	100

Note: When all sample farmers are considered: 43% (subsidy); 26% (agrodealer); 22% (family, neighbors, stocks), followed by other sources.
Source: Authors, based on data from HarvestPlus Maize Seed Adoption Survey, Zambia, 2011

6. CONCLUSIONS

The current emphasis on input subsidy programs in a number of Sub-Saharan African countries was stimulated by interest in Malawi's program, which has been the most extensively studied. Nonetheless, this emphasis circles back in some respects to previous policy models of the 1960s and 1970s, which proved to be unsustainable. Recent research has highlighted some of the challenges of targeted subsidy programs, and several studies have shown how subsidies reduce the commercial demand for inputs, undermining efforts to privatize input industries and engage smallholder farmers in input markets. Some studies have questioned the extent to which subsidies address the needs of poor smallholders.

This paper tests the hypothesis that the hybrid maize subsidy in Zambia is selectively biased due in part to its delivery mechanism and the self-selection of farmers who are able or choose to exercise their claim. We then classify farmers into three groups along two dimensions: receipt of seed subsidy and predicted probability of growing hybrid maize. We compare poverty rates, classify social and economic characteristics of households in these groups, and identify their seed and information sources. Our purpose is to highlight demand segments that may be of interest in designing strategies for the diffusion of vitamin A-rich maize among smallholder farmers in Zambia, both through the existing subsidy program and alternative means.

Our understanding of FISP in Zambia is that at its genesis it was not designed to reduce poverty but to "re-boot" maize productivity following its decline in the 1990s. Thus there was no explicit focus on the nation's poorest maize farmers but on farmers who had the capacity and resources to use inputs effectively. In the current design, farmers must be members of registered farmers groups to purchase inputs at the subsidized price. Naturally, some choose to sell their rights to the farmers who are willing to pay for them. In fact, the research conducted so far and shown in this paper supports a maintained hypothesis that the subsidy is received by farmers who are better off in terms of land, income, and/or assets. Interestingly, female- and male-headed households have the same chances of receiving the subsidy. Beneficiaries are more likely to live in AEZ III than in AEZ IIA or AEZ I. Many of them also purchase seed commercially, so the subsidy augments the area they would already have planted to hybrid maize.

Accordingly, econometric findings demonstrate that whether or not the farmer receives a subsidy is exogenous, or recursive, in hybrid seed use decisions. Moreover, a sizeable proportion of farmers (61 percent) who do not receive a maize seed subsidy have a high predicted probability (over 90 percent) of growing hybrids. Thus, there is a potential demand for hybrid seed that is not met through the subsidy program. These farmers also appear to be poorer than those who received the subsidy and have the same high predicted probability of growing hybrids. Our findings therefore support the hypothesis that the subsidy, as designed, delivers seed selectively.

The mandate of HarvestPlus is to target poor rural households who grow and consume staple food crops, which provide most of the calories they consume. Considering the strong associations between income and dietary quality (Hoddinott and Yohannes 2002) and resulting nutritional outcomes, reaching these households with nutrient-rich staple crops, such as vitamin A maize, could contribute a greater health impact in a cost-effective manner. Designing strategies that understand these farmers and how to best reach them is essential for the success of the HarvestPlus program. Our preliminary analysis has identified a group of farm households that do not currently receive subsidized maize seed but have a high predicted demand for hybrid seed. This group is clearly less favored in terms of land, social capital, and information. Although there is no difference in the proportion of households headed by women, there is a difference in the proportion of seed decisionmakers who are women, which is higher for the excluded group.

Given its mandate, our analysis leads us to recommend that HarvestPlus should consider not only participating in the FISP voucher program but also designing or taking part in complementary programs that reach farming households excluded from FISP. After the subsidy program the second most important source of maize seed is agrodealers. Zambia's new voucher system, which is in its pilot phase this planting season (2012/13), may also enable a better assessment of hybrid-specific demand among smallholder farmers, increasing seed types that meet farmers' objectives and production environments, including both biophysical and economic considerations. The new system will more directly engage agrodealers, but other mechanisms might also be developed by HarvestPlus.

There is also some evidence that despite the importance of the formal maize seed sector in Zambia, informal, farmer-to-farmer exchanges constitute a third major source of maize seed. This avenue might be tapped via local non-governmental organizations or social networks such as churches or other community groups. The data also suggest informational constraints among farmers not qualifying for subsidies but with a high probability of growing hybrid seed. Across all groups, health clinics are a significant source of information; therefore, HarvestPlus might also consider working through public health initiatives.

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