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Is Older Better?
Maize Hybrid Change on Household Farms in Kenya

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Abstract

A globally-recognized maize "success story" since the 1970s, Kenya's first maize hybrid diffused faster than did hybrids in the U.S Corn Belt during the 1930s-1940s. Today, a hybrid released in 1986 still dominates on farms in Kenya, despite the dramatic increase in the number of hybrids, breadth of seed suppliers, and range of hybrids sold as seed markets liberalize. Claims of stagnating yields and stagnating adoption are offset here, at least in part, by longitudinal survey data showing rising yields and adoption rates on farms. However, as the overall percent of maize farmers growing hybrids tops 80 percent and the seed industry matures, the slow pace of hybrid replacement may still be cause for concern. This paper begins an exploration of factors affecting the age of hybrids on farms in Kenya. We find a strong farmer response to the seed-to-grain price ratio—evidence of a commercial orientation even on household farms, and also of the need to "get (seed) prices right" in the industry.

1.0 Introduction

Kenya has been touted as global maize "success story" for decades (Gerhart 1975; Byerlee and Eicher 1997; Smale and Jayne 2010). Released on the eve of independence, H611, Kenya's first maize hybrid, a unique, varietal hybrid with Ecuadorean and Kenyan parentage, diffused "at rates as fast or faster than among farmers in the U.S. Corn Belt during the 1930s-1940s"(Gerhart 1975: 51). Paradoxically, policy researchers have more recently lamented that earlier gains in maize productivity have not lived up to their potential (Karanja 1996; Lynam and Hassan 1998; De Groote et al. 2005). Rates of growth in maize production have not kept pace with demand, in large part driven by population growth, so that the country's import bill has risen during recent years (Kirimi et al. 2011).

The perception of stagnating maize productivity is generally supported with reference to FAO data, although data based and repeated surveys of a panel of farmers (Tegemeo, from 1997) do indicate yield increases. Disagreement among data sources could reflect different spatial representation, especially as maize growing expanded into more marginal areas for production, or differences in temporal representation, since weather conditions are variable under Kenya's rainfed production conditions.

Numerous explanations have been advanced for stymied progress. For examples, breeders may have failed to surpass the quality of earlier releases, thwarting gains in yield potential of maize hybrids (Karanja 1996); rising population densities in rural areas may have created inefficient farm size, exacerbating a long-term, secular decline in soil fertility (Lynam and Hassan 1998; Byerlee and Heisey 1997); economic liberalization probably generated uncertainty; and seed liberalization has been partial, curtailing the availability of improved hybrid seed (De Groote et al. 2005). Years ago, Gilbert et al. (1993) pointed out that reported yields understate progress made in counteracting yield losses due to biotic and abiotic stresses through maize improvement (gains from maintaining yields, as compared to augmenting yield potential). Ariga and Jayne (2010) point out that changes in the proportion of intercropped land cause FAO data on maize yields, which is drawn from official MoA estimates, to be biased downward.

This paper begins an effort to disentangle the causes and consequences of Kenya's maize productivity dilemma by focusing on one component: the age of hybrids grown on farms. Most improved maize seed grown in Kenya has been hybrid. By a hybrid's "age" we mean the number of years the hybrid has been grown by farmers since its initial year of introduction. Kenyan farmers generally have a long experience with hybrid seed, although they may not choose to grow a hybrid each year. For example, Tegemeo 2010 survey data confirms that on average, farmers began growing improved maize in 1991, with a modal year of 1980. The earliest year among respondents was 1958, and only 4 percent had never grown improved maize. Recently, in a comprehensive analysis of Tegemeo's panel data, Suri (2011) concluded that farmer learning processes had little to do with whether a farmer chooses to grow a hybrid in any particular year, given the long experience of farmers with hybrid seed in the major maize-growing zones of Kenya.

We argue that it is not adoption of maize hybrids per se which determines the effect of hybrid seed on maize productivity in Kenya today, but replacement of old by new hybrids. Obsolescence of germplasm is one reason why replacing one hybrid or modern variety by another, and not just replacing its seed, is thought to be necessary for yield progress. For example, this "second stage" of adoption contributed a large proportion of the total economic gains from use of modern wheat seed during and after the Green Revolution in Asia (Byerlee and Traxler, 1995). Slow change of wheat varieties grown by farmers has offset the positive productivity effects of diversifying the genetic base of wheat breeding during the post-Green Revolution period in Punjab, India (Smale et al. 2008).

Based on a 1992 national survey, Hassan (1998) found that the area-weighted average age of all modern varieties grown by farmers (improved open-pollinated and hybrids) was 23 years, although it was only 10 years among hybrid growers, who were concentrated in the higher potential areas. To compare Kenya once again with the US, recent analyses by Magnier et al (2010) indicated that the average "survival" of a maize hybrid on the seed market was only 5 years, and the market share of the typical hybrid peaks at 2 to 3 years.

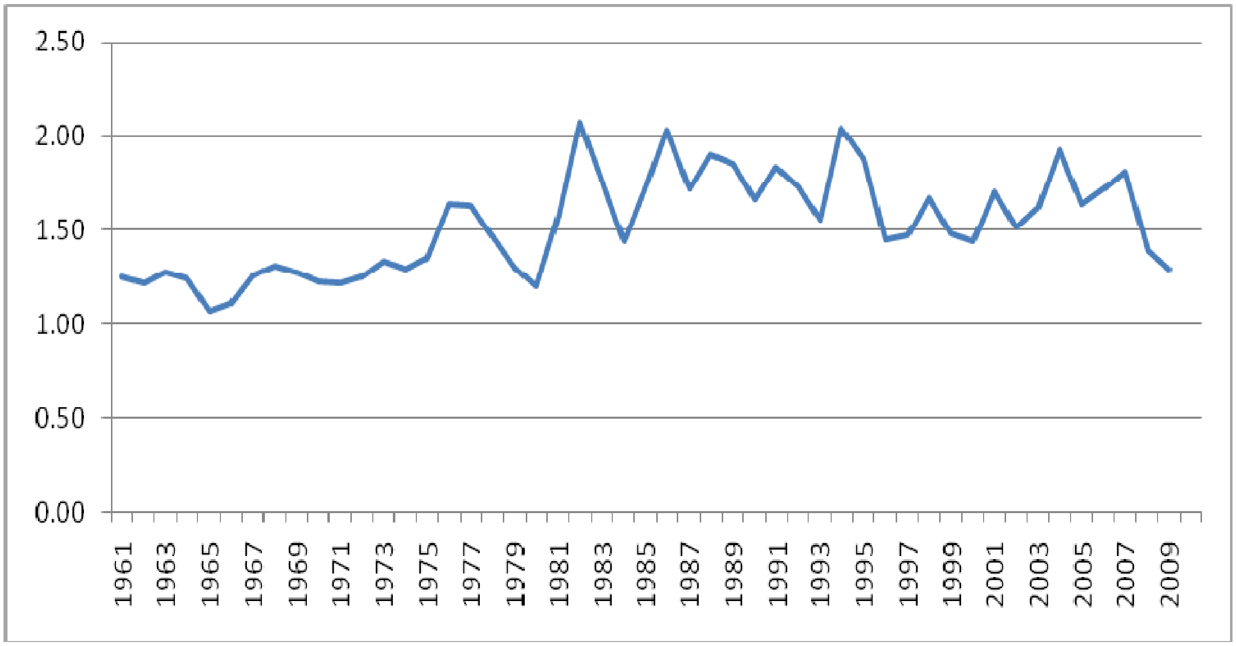
In this paper, we explore the age of maize hybrids on farms in Kenya and its determinants. In the next section we summarize contextual data on maize yields, use of maize hybrids, and ratios of input to output prices, which are a major determinant of the on-farm profitability of using hybrid seed (Heisey et al. 1998). We then present the data and analytical methods we use to describe and explain hybrid age on farms. Results are presented in the fourth section, followed by a concluding section and policy recommendations.

2.0 Context

2.1 Maize Yields

According to the Food and Agriculture Organization (FAO) of the United Nation's data, national average maize yields are variable in Kenya, with endpoints in 1961 and 2009 that show discouraging similarity (1.25 and 1.29, shown in Figure 1).

Figure 1: National Average Maize Yields (t/ha) in Kenya, 1961 to 2009



Source: FAOSTAT data (www.FAOSTAT.org)

National production growth rates are decomposed by area and yield in Table 1. During the episodes of broad-based growth (1965 to 1980) in Kenya, the growth rate in maize production was 3.3%, and a sizable component of the growth rate was attributable to yield (44%) as compared to expansion in area. During episodes of decline (1990-2009), the production growth rate dropped to 0.84%, with a negative growth rate in yield, which was partially offset by an expansion in area. Over all years reported in the FAO data, the maize production growth rate is 1.71%, of which 58% is explained by a growth in area, and a smaller, though important component (42%), by growth in national average yields.

Table 1: Growth rates of maize area, yield and production in Kenya

Period	**Area Average growth rate (%)**	**Yield Average growth rate (%)**	**Production Average growth rate (%)**
1965-80 ("growth")	1.86	1.44	3.30
1990-2005 ("decline")	1.26	-0.42	0.84
1961-2009	1.00	0.72	1.71

Source: Smale and Jayne 2010; FAOSTAT May 17, 2011.

As a point of contrast, coefficients of yield variation, adjusted for trend, are lower in Kenya than in the other major maize-producing and consuming countries in East and Southern Africa (Malawi, Zambia and Zimbabwe). It may also be worth noting, however, that although the growth rate in maize production was equal to the growth rate in the index of all agricultural production in Kenya during the 1965 to 1980 period, it was less than half the overall growth rate during the later period (Smale and Jayne, 2010: 103).

Average yields for a balanced panel of farmers in the major maize-producing zones of Kenya are shown in Table 2, drawn from Tegemeo's data. While 2007 appears to have been a particularly good year, the pattern in the data is persistently upward, equivalent to an average annual growth rate of about 2.4%. Yield gain is statistically significant over the 13-year period and from one wave to another with pairwise t-tests in all years except for 2000-2004, when gains were negligible and 2007-2010, when average yields declined.

Suri (2006) also presents yield distributions conditional on use of hybrids. The modes of distributions, and both tails of the distributions, lay to the right for all hybrid users relative to non-users in 1997, 2000, and 2004, suggesting that yields for maize hybrids dominate in the first-order stochastic sense.

Table 2: Average Maize Yields (kg/ha) for a Balanced Panel of Farmers in the Major Maize-Producing Zones of Kenya, by Growing Season, 2000-2010

Year	Both seasons	Main season	Dry season	Total maize plots
2000	1,649	1,965	1,021	2,181
2004	1,729	2,063	1,092	2,105
2007	2,175	2,449	1,708	2,090
2010	1,934	2,090	1,721	2,205

Source: Tegemeo Institute panel survey data, 2000 – 2010. Yields for first three columns are for major maize fields only. Total maize plots includes all maize plots, both seasons.

Comparing CIMMYT/KARI data collected in 1992 to nationally representative data collected in maize producing zones of Kenya in 2002 (in independent samples), De Groote et al. (2005) found that yields have increased over time in all zones, except for the dry mid-altitude zone. However, only the 2002 yield in the moist transitional zones came close to the national average of 1.5 ton/ha (Figure 1). Tegemeo data (Table 2) appear to be similar to national averages in 2000 and 2004, but higher than national averages in 2007 and 2010 (Figure 1), considering both seasons.

Thus, whether a panel or independent cross-sectional samples are employed, farm survey data seem to depict a more encouraging change in maize productivity than do national data, although questions remain concerning comparative statistical representation and measurement.

2.2. Adoption of Hybrid Maize

Adoption estimates vary by definition of adoption, year, and national coverage. The percentage distribution of seed lots[1] by type has changed over each successive year in the Tegemeo panel (Table 3). Use of hybrid seed has generally increased, except in 2004, when a larger share of maize seed lots were improved open-pollinated varieties. A very minor percentage of hybrid seed lots have been retained (recycled), and in 2010 nearly four out of five seed lots planted were new hybrid seed. This is an important finding regarding the demand for seed and the commercial orientation of growers, since past research has shown that saving and replanting F1 maize hybrids has been common among smallholder growers in Eastern and Southern Africa (Morris et al. 1999). The percent of seed lots is not the same as the percent of farmers, since some farmers grow more than one seed. Local maize varieties persist, although in 2010, they represented only a quarter of seed lots planted, compared to about at least a third in preceding survey years. It is to be expected that these are grown on land that is less suitable for maize, or because they have particular traits of interest to farm households.

Differences between seasons are pronounced in each survey year. Hybrids grown in the short season are more likely to be retained seed than in the main season, and local varieties are more frequently grown.

Table 3: Percent of Maize Seed Plots Planted by Seed Type, Season and Year

		Hybrid						
		New	Retained	All	Improved variety	Local variety	Total	N
2000								
	Main	62.3	5.2	67.5	2.7	29.9	100.0	1524
	Short	46.2	7.5	53.7	2.0	44.3	100.0	751
	Total	57.0	5.9	62.9	2.5	34.6	100.0	2275
2004								
	Main	55.6	4.2	59.8	9.1	31.0	100.0	1569
	Short	30.9	7.6	38.5	12.0	49.4	100.0	764
	Total	47.5	5.3	52.8	10.1	37.1	100.0	2333
2007								
	Main	68.3	2.8	71.1	1.2	27.7	100.0	1582
	Short	45.0	6.0	51.0	2.0	47.1	100.0	852
	Total	60.1	3.9	64.0	1.5	34.5	100.0	2434
2010								
	Main	77.9	0.8	78.7	1.3	20.0	100.0	1440
	Short	61.1	3.9	65.0	1.8	33.1	100.0	939
	Total	71.3	2.1	73.4	1.5	25.2	100.0	2379

Source: Tegemeo Institute panel survey data, 2000 - 2010Note: some farmers plant more than one lot of seed. Includes both short and main season. Distribution differences are significant at 5% between each pair of

[1] A seed lot is the physical unit of seed the farmer uses to reproduce the maize variety or hybrid, typically associated with a single field, and reported in that way in the Tegemeo data.

successive years with Wilcoxon Signed Rank test for related samples. Distributions are different within years at 5%with Chi-squared test.

Suri (2006) presents adoption figures from the Tegemeo panel through 2004 as the hybrid share of maize seed planted, illustrating the stability of aggregate adoption (between 60 and 70 percent), and differences by region. Hybrid shares of maize seed planted are highest in Central and Rift Valley Provinces, rising substantially in Western Province between 1997 and 2004, at an intermediate scale in Eastern Province, and lowest in Nyanza and Coastal Provinces.

CIMMYT surveys of hybrid seed use in Kenya, which are based on seed sales as compared to farm surveys, indicated that an estimated 62% of maize area was planted to hybrids in 1990 and 1996, and 68% in 2006 (Langyintuo et al. 2010, Hassan et al. 2001, Lopez-Pereira and Morris 1994).

Based on the farm surveys described above, De Groote et al. (2005) found that between 1992 and 2002, improved seed use had become nearly universal in the highland tropics and moist transitional zone, only attaining 40 percent in the drylands, remaining close to 50 percent in the moist mid-altitude zone, and doubling to 75 percent farmers in the coastal lowland tropics. Two popular hybrids, specifically developed for the coastal area, had recently been released.

Tegemeo's 2010 survey data provides estimates which are roughly consistent with De Groote et al's (2005), except for a farmer adoption rate of only 40 percent in the Coastal Lowlands (Table 4). Other than a low adoption rate of 61% in the Lower Midland (3-6), rates in all other zones range from nearly 90 to 100%. Given the climatic features of the environments, these rates may be considered as the maximum attainable for the initial switch from farmers' varieties to hybrids. Additional but very minor percentages of farmers grow improved open-pollinated varieties. Note that the higher rates of adoption per farmer than per seed lot reveal that some farmers grow more than one hybrid, even within a season. Farmers surveyed during the 2009-10 main season planted up to six maize fields with hybrids.

Table 4: Percent of Households Growing Hybrid Seed in Main Season, by Agro-ecological Zone, 2009-10

Agro-ecological zone	**N**	**Maize growers planting hybrids 2009-10 (%)**
Coastal Lowland	77	40.3
Lowland	44	88.6
Lower Midland (3-6)	253	60.9
Lower Midland (1-2)	146	89.7
Upper Midland (2-6)	253	92.5
Upper Midland (0-1)	242	89.3
Lower Highland	236	94.9
Upper Highland	41	100.0
All zones	1292	82.8

Source: Tegemeo Institute survey data, 2010

Based on a 1992 national survey, Hassan (1998) found that the area-weighted average age of all modern varieties (improved open-pollinated and hybrids) grown by farmers was 23 years. Tegemeo panel data suggest that the area-weighted average age of modern maize varieties dropped substantially during the 2000s (Table 5). In all zones taken together, average ages are 16.5 to 18 years, and area-weighted averages are slightly lower—indicating that newer materials are introduced and older materials occupy smaller and smaller shares of maize area. The slight rise in 2010, which is statistically significant (5%), may mean that more seed of an older, popular hybrid was made available to more farmers through better seed marketing. Some statistically significant differences between mean variety ages (area-weighted means cannot be tested because of construction) are apparent, with the lowest average variety age in the Upper Highland zone, and the highest in the Coastal Lowland, Lowland, Upper Midland (0-1), Lower Highland and Lower Midland (1-2) zones .

Recycled hybrids are significantly older (at 5%) than newly purchased, as can be expected. Improved open-pollinated varieties have generally been released more recently, with the exception of old favorites like Katumani (at 5%). Kenya's public breeding program, followed by private seed companies, has long been more active in breeding hybrids, and many of Kenya's hybrids are varietal. H614D, released in 1986, represented 55 percent of all modern maize seed lots planted by farmers surveyed by Tegemeo in 2004, 44 percent in 2007, and 43 percent in 2010.

Table 5: Age of Modern Maize Hybrids and Varieties Grown by Farmers, by Agro-ecological Zone and Year, Main Season

Agro-ecological zone	Average age					Area-weighted average age		
	2004	2007	2010	All years		2004	2007	2010
Coastal Lowland	21.1	18.5	19.5	19.6	a	16.0	18.8	18.8
Lowland	24.1	17.1	18.4	19.7	a	21.2	18.5	17.2
Lower Midland (3-6)	16.8	14.3	15.2	15.3	b	17.9	12.4	13.5
Lower Midland (1-2)	16.3	16.1	17.8	16.7	b	15.6	17.0	18.3
Upper Midland (2-6)	16.2	14.8	16.9	16.0	b	15.7	13.8	18.0
Upper Midland (0-1)	17.4	19.3	20.4	19.1	a	17.5	19.7	20.6
Lower Highland	14.9	16.9	20.2	17.3	b	13.8	15.4	17.8
Upper Highland	12.9	15.1	16.5	14.9	c	11.7	12.3	14.8
All zones	16.5	16.5	18.3	17.1		15.4	14.9	17.3

Source: Tegemeo Institute panel survey data, 2004 - 2010

Only 4.4% are improved open-pollinated varieties; 95.6 are maize hybrids, of 3330 total seed lots planted
Differences within groups (a,b,c) are not statistically significant, but are significant between groups.
Source: Tegemeo survey data. Variety names not recorded in 2000 or 1997.

Hassan (1998) found only 12 hybrids grown in 1992, and all had been released and were owned by KARI. Considering only the years 2001-2006, over 90 modern maize hybrids and varieties were released in Kenya (Nyoro et al. 2006). These were the intellectual property not only of KARI and KSC, but also Pannar, Pioneer, Lagrotech, Western Seed, Monsanto, Agri-Seed, SEEDCO, and other companies. Tegemeo data confirm that the numbers of maize hybrids grown in Kenya have increased dramatically; including all zones, numbers on hybrids increased from 33 in 2004 to 50 in 2010 (Table 6).

Table 6: Number of Modern Maize Hybrids and Varieties grown, by Agro-ecological Zone and Year

Agro-ecological zone	Count		
	2004	**2007**	**2010**
Coastal Lowland	5	6	7
Lowland	9	14	16
Lower Midland (3-6)	15	19	20
Lower Midland (1-2)	14	20	22
Upper Midland (2-6)	20	18	26
Upper Midland (0-1)	13	10	24
Lower Highland	15	25	22
Upper Highland	5	9	11
All zones	33	50	50

Source: Tegemeo Institute panel survey data, 2004 - 2010

2.3. Seed-to-Grain Price Ratios

The seed to grain price ratio is a major incentive for use of hybrid maize seed, whether the seed is replaced as recommended, and whether a farmer shifts from one maize hybrid to another. Official time series data suggest that maize seed to grain price ratios and rural wage to grain price ratios moved similarly through the 1980s in Kenya. In the early 1990s, seed to grain, rural wage to grain, and fertilizer to grain price ratios rose and fell abruptly relative to previous magnitudes (De Groote et al. 2005).

Seed to grain price ratios, as calculated based on the district median grain price and prices reported by farmers who purchased seed and sold grain, are reported in Table 7 based on Tegemeo survey data in 2004, 2007, and 2010. Sample sizes are much smaller for farmers who sell grain, and for seed of improved varieties compared to hybrids. As expected, ratios are several times as high for improved seed relative to seed of local varieties and mean ratios for hybrids appear to drop in 2010 relative to the previous two survey years, when means were 10-11. Because inflationary factors that affect seed also affect grain, the ratios do not need to be deflated. However, economic factors, and price policies, can shift their values.

The National Cereals and Produce Board (NCPB) reports uniform seed prices throughout the country, by seed company. The Kenya Seed Company (KSC), which controls 80% of the formal maize seed market, also sets uniform prices countrywide for its seed. Thus, variation in the seed prices reflects other factors. Regression of the kg-weighted average seed prices paid by farmers indicates that the factors related to distances and trader densities, hybrid age, and the specific location of the household, are statistically significant in explaining variation (Table 8).

Table 7: Maize Seed-to-Grain Price, by Seed Type and Year

		Farmer seed price/district grain price			Farmer seed price/ farmer grain sales price		
		Hybrid	Improved variety	Local variety	Hybrid	Improved variety	Local variety
2004	N	1107	183	180	558	47	27
	mean	10.36	10.30	1.75	11.12	10.66	1.91
	Std.Dev	1.42	3.81	0.52	5.04	5.18	0.62
2007	N	1432	24	96	674		20
	mean	10.97	9.64	2.41	11.74		2.46
	Std.Dev	2.64	2.88	3.17	5.59		2.33
2010	N	1624	22	106	532		14
	mean	6.70	7.42	1.72	7.21		1.76
	Std.Dev	1.73	2.06	0.67	4.05		0.77

Source: Tegemeo Institute panel survey data, 2004 - 2010
Note: Hybrid includes only newly purchased, but this is not always clear for IOPVs
Empty cells implies sub-sample counts under 20

The National Cereals and Produce Board (NCPB) reports uniform seed prices throughout the country, by seed company. The Kenya Seed Company (KSC), which controls 80% of the formal maize seed market, also sets uniform prices countrywide for its seed. Thus, variation in the seed prices reflects other factors. Regression of the kg-weighted average seed prices paid by farmers indicates that the factors related to distances and trader densities, hybrid age, and the specific location of the household, are statistically significant in explaining variation (Table 8).

Table 8: Regression of Hybrid Seed Prices Paid by Farmers in 2010

Variable	Coef.	Std. Err.	t	P>t
Coastal Lowland	-68.359	6.768	-10.10	0.0000
Lowland	6.673	4.519	1.48	0.1400
Lower Midland (3-6)	22.499	3.646	6.17	0.0000
Lower Midland (1-2)	18.216	3.467	5.25	0.0000
Upper Midland (2-6)	12.008	3.295	3.64	0.0000
Upper Midland (0-1)	6.269	3.327	1.88	0.0600
Lower Highland	0.687	3.339	0.21	0.8370
Km to nearest town	-0.202	0.069	-2.93	0.0030
Ksh to transport 90-kg bag of maize	0.004	0.013	0.29	0.7710
Km to nearest NCPB outlet	-0.080	0.037	-2.15	0.0320
Area-weighted hybrid age	-0.500	0.077	-6.47	0.0000
Latitude of household	-17.041	1.280	-13.31	0.0000
Longitude of household	2.884	0.739	3.90	0.0000
Constant	30.526	26.962	1.13	0.2580
Number of obs	998			
F(13, 984)	67.34			
Prob > F	0.0000			
R-squared	0.4708			

Upper Highland is omitted zone
Source: Tegemeo Institute survey data, 2010

Heisey et al. (1998) provide some useful interpretation of the magnitude of these ratios, based on break-even yield gain curves constructed by Byerlee et al. (1993) to illustrate the expected profitability of hybrid maize for smallholder farmers. At a low seed to grain price ratio of 5:1, the yield advantage of hybrid seed need not be large for the hybrid to be attractive, even if farmers' yields are low. At a high seed to grain price ratio of 20:1, the yield advantage must be fairly large for a hybrid to be attractive. They conclude that low seed to grain price ratios are needed to encourage farmers to adopt hybrids during the emergence and growth phases of the maize seed industry, until the market is well established. Thereafter, these ratios often rise and stabilize in the range of 25:1 to 30:1. This pattern occurred in the US, where the ratio has surpassed 30:1 but was around 10:1 from 1940 to the late 1960s. If farmers are net consumers, as in the case of many farmers in Kenya, the relevant price would be the grain purchase price, which is generally higher than the grain sales price, particularly in the season of purchase. Returning to Figure 2 and Table 7, Kenyan seed to grain price ratios seem to have followed a fairly favorable path for hybrid seed use, ranging from under 5 to slightly above 10 over the past decades. Ratios are close to 10:1 in the early 1990s and again in through the mid-2000s. Of course, the fertilizer-responsiveness of most maize hybrids complicates this equation, since fertilizer is the more costly input of the two. In the survey data, only the skewed tails of the seed-to-grain price distributions are above 20:1, and these may be measurement errors.

Wilcoxon signed rank tests for related samples indicate that the overall distributions of hybrid seed to grain price ratios based on farmers sales prices as compared to district means are significantly different only in 2010. Distributions based on the district median grain price, which are based on larger samples of hybrid seed prices, show medians close to the mean in 2010 (6.2), 2007 (10.4) and 2004 (10.5). Modes are 5.4, 9.4 and 9.4, respectively. Ratios thus changed substantially between 2007 and 2010—favorably for hybrid maize growers. Estimates from Tegemeo panel show a very large increase in the maize grain price in 2010 relative to the seed price (Table 9). The large increase in maize price occurred after the post-election violence in 2008 and continued through the 2009 spikes in world food prices. It is during these periods that Kenya also experienced depressed rainfall which affected local maize supply. All these factors contributed to the observed increase in maize prices. Seed prices, however, did not change much owing to the KSC's practice of setting uniform prices for its seed.

Table 9: Changes in Hybrid Seed and Grain Prices, 2004, 2007, and 2010

Year	Seed price (Ksh/kg)	Grain price (Ksh/kg)	% change in seed price	% change in grain price
2004	133.1	13.0		
2007	131.2	12.3	(1.48)	(5.52)
2010	136.3	20.7	3.93	68.30

Source: Tegemeo Institute panel survey data, 2004-2010

3.0 Methods and Data

3.1. Data

The data employed here are from the Tegemeo/MSU Panel Household Surveys for 1999/00, 2003/04, 2006/07, and 2009/10 cropping years, although seed varieties were not reported in the 1999/00 survey. The panel household survey was designed by Egerton University/Tegemeo Institute, with support from Michigan State University. The sampling frame was prepared in consultation with the Kenya National Bureau of Statistics (KNBS) in 1997. Twenty-four (24) districts were purposively chosen to represent the broad range of agro-ecological zones (AEZs) and agricultural production systems in Kenya. Next, all non-urban divisions in the selected districts were assigned to one or more AEZs based on agronomic information from secondary data. Third, divisions were selected from each AEZ proportional to the size of population. Fourth, within each division, villages and households were randomly selected. A total of 1,578 households were selected in the 24 districts within seven agriculturally-oriented provinces of the country. The sample excluded large farms with over 50 acres and two pastoral areas. The first survey was conducted in 1997, with a much more restricted survey instrument than those applied in later years.

The attrition rate for the panel was 21% in 2010 compared to the initial survey, conducted in 1997. Reasons for non-participation in subsequent surveys were recorded. Some of the main reasons for this attrition are related to death of household heads and spouses leading to dissolution of households, and relocation of households from the study areas. Households in Turkana and Garissa districts were not interviewed after 2000.

Only the 2010 survey data were used for the regression analysis presented here.

3.2 Methods

Heisey et al. (1998) modeled the economics of hybrid maize adoption in developing agriculture conceptually and empirically based on a cross-country comparison of national rates of use. The authors identified seeding rates, the seed-to-grain price ratio, yield advantages of hybrids relative to other maize types grown, the cost of capital, learning and risk as major determinants of the demand for hybrids. Since their data were national and their goal was to analyze global differences in the industry as a whole, the only variable they included to measure farm-level profitability was the seed-to-grain price ratio. To incorporate other factors affecting demand and supply among individual farmers, they included production environment, region, national income per capita, average farm size, and proxies for the development of road and input infrastructure.

For our purposes, despite the long history of growing maize hybrids in Kenya, and considerable progress in maize grain and seed market liberalization, most farmers probably do not fit a decision-making model based entirely on profit maximization. Of the farmers who planted maize in 2010, only 28 percent overall sold maize, although the percentage corresponds roughly to adoption rates, ranging from 3 in the Coastal Lowlands to 73 in the Upper Highlands. Farmers in the Upper Highlands sold an average of 8 tons (Table 10).

Table 10: Percent of Hybrid Maize Growers Selling Grain in 2010 and Average Amounts Sold

Agro-ecological zone	Number of hybrid growers selling maize		Average amounts sold in 2010 (kgs)
	Number	percent	
Coastal Lowland	2	2.6	270
Lowland	10	22.7	432
Lower Midland (3-6)	43	17.0	588
Lower Midland (1-2)	63	43.2	1270
Upper Midland (2-6)	97	38.3	3973
Upper Midland (0-1)	84	34.7	548
Lower Highland	37	15.7	2986
Upper Highland	30	73.2	8179
All zones	366	28.3	2456

Hybrid includes retained and newly purchased hybrids
Source: Tegemeo Institute survey data, 2010

Thus, we motivate our regression model with the model employed by Heisey et al. (1998), but also the framework of the theory of the household farm (Singh, Squire and Strauss 1986), which includes profit-maximization as a special case when markets are perfect and production and consumption decisions are separable. When they are not, seed decisions are the outcome of choices of consumption amounts and product combinations to maximize utility, subject to market constraints. Formal derivations of crop variety choice decisions based on the theory of the household farm are found in Meng (1997), Van Dusen (2000) and Edmeades et al. (2003).

In this framework, seed-to-grain price ratios faced by the household are endogenous functions of the household characteristics that affect access to transaction information, credit, transport and other market services, such as human capital, farm assets, and experience, as well as the observed seed-to-grain price ratio. The observed seed-to-grain price ratio itself depends on physical market infrastructure and the variety grown, and whether or not there are premia paid for grain of a certain quality. Explanatory variables are defined in Table 11.

Table 11: Definition of Variables Based on Conceptual Model of Household Farm

Conceptual variable	Operational variable	Sample mean	Standard deviation
Dependent			
Grow maize hybrid	0=do not grow hybrid, 1=grow hybrid	0.82	0.39
Scale of maize hybrid use	Total kgs hybrid maize seed planted in 2009-10 main season	18.38	8.70
Slowness of hybrid change	Area-weighted average age of maize hybrids planted in 2009 main season. Age=2010-release year	12.42	28.42
Independent			
Seed-to-grain price ratio	Kgs-weighted ratio of seed price paid to grain price received (ksh)	6.57	1.45
Education	Formal educational attainment of household head (years)	4.74	7.71
Widow	Recognized head of household is a female and widow=1, 0 otherwise	0.23	0.42
Experience	2010-first year growing hybrid maize	18.45	12.30
Farm land owned	Total acres owned in 2009	5.29	8.99
Total value of assets (2010 Ksh)	Value of all farm physical and livestock enumerated in 2009	360742.60	838023.90
Rainfall stress 2008-9	Fraction of 20 day periods with <40mm rain during main rainy season preceding the survey season	0.42	0.29

We model seed outcomes in terms of the household decision to grow a hybrid (0,1), the scale of hybrid seed use on the farm (total kgs of hybrid seed planted) and the age of the hybrid planted (current year minus the release year). Hybrid age is an indicator of hybrid turnover that is estimable with a single time period of data. Since farmers may grow more than one hybrid, we weighted the age of each hybrid grown by the proportion of total hybrid acreage planted, and computed the acreage-weighted average age. Seed and grain prices were also weighted by amounts purchased and sold.

Human capital variables include the highest educational level attained by the household head, the experience of the household head growing hybrid maize, and whether the household is headed by a man or a widowed woman. Age of the household head is highly correlated with years growing hybrid maize, and is not included. Financial capital includes farm land owned and assets, measured as the current total value of all farm physical and livestock assets enumerated in 2010.

Because receipt of cash credit, a financial asset, is potentially endogenous with the decision to grow hybrid seed, we considered including its predicted value. Cash credit is highly correlated with asset variables, but not significantly correlated (5%) with whether or not the household chose to grow hybrid maize. As a consequence, we did not include the variable.

Analysis by Chamberlin and Jayne (2010) has confirmed that the density of maize traders in villages is a more accurate indicator of grain market access than distance. As might be expected, observed seed-to-grain prices are significantly correlated with the distance to the nearest seller of certified maize, the number of maize grain traders in the village, and agro-ecological zone, as well as the latitude and longitude of the farm household. These variables were excluded from the regressions, but may be interpreted as a cluster. In addition, rainfall amounts in a season were significantly correlated with rainfall in the previous season, and rainfall amount in each year was closely related to moisture stress. Only moisture stress during the main season of 2008-9 was retained in the analysis.

As described by Rickert-Gilbert, Jayne and Chirwa (2011) in the case of fertilizer use, there are three basic options for estimating the first two seed use decisions. The two-stage Heckman model was long used for differentiating between the decision to adopt a new seed variety and the area planted in adoption models, but the model is more suitable for unobserved values of the dependent variable than for modeling a "zero" input choice that is optimal (a corner solution). The Heckman model was originally proposed to control for bias in wage estimates due to sample selection in labor markets. The Tobit model better represents a corner solution, but it imposes the same structure on the process that generates the decision to grow hybrids and the total amount of seed planted. The double-hurdle model has recently been widely used to estimate adoption decisions, and is preferred because of its flexibility (e.g, for maize, Langyintuo et al. 2003). The statistical fit of the double-hurdle model can be compared to that of the Tobit model by comparing the likelihood ratios of probit and truncated regression (the unrestricted model, or two phases of the double-hurdle model) to that of the (restricted) Tobit model.

The third regression, on hybrid age, was estimated with ordinary least squares. Given the pronounced peak of 24 years in this variable (corresponding to a household decision to plant only one hybrid in the H611-614D series, particularly H611), this regression was also estimated without the 24 year peak to ascertain whether it remained relevant for other observations.

4.0 Results

Results for the double hurdle model are shown in Table 12. Given the high rates of hybrid adoption in Kenya, t-tests on regression coefficients are similar for ordinary least squares and probit regressions, and the decision to grow hybrid maize is not particularly well-explained.

Higher educational attainment of the household head positively and significantly affects the likelihood a household will grow hybrid maize, as does past experience. Farmers who own more land are more likely to grow hybrid maize, but wealth, as measured more generally by the value of assets, has no significance. Women widows are as likely as male-headed households to grow hybrid maize. Rainfall stress in the preceding season, which is correlated with past rainfall patterns, does not discourage farmers from planting maize hybrids.

The seed-to-grain price ratio is statistically significant. The higher the prices paid for seed relative to grain in the village, the lower the chances a farm household will grow a hybrid. This finding suggests that, despite the high rates of hybrid maize adoption in Kenya, there is still room to expand initial adoption of hybrid maize in Kenya—at least from the viewpoint of farmer responsiveness to effective prices and factors that have long been associated with adoption of improved seed—education and farm size. Of course, whether or not it makes sense from a farming system perspective is another matter.

Table 12: Determinants of use and Amount of Hybrid Maize Seed Planted in 2009/10

Variable	**Coeff**	**Std. Error**	**z**	**P>|z|**
Grow hybrid				
Education	0.0191	0.0077	2.48	0.01
Widow	-0.0832	0.1347	-0.62	0.54
Experience	0.0244	0.0047	5.18	0.00
Farm land owned	0.0300	0.0149	2.01	0.04
Asset value	-7.88e-08	1.16E-07	-0.68	0.50
Seed-to-grain price ratio	-0.0789	0.0389	-2.03	0.04
Rainfall stress 2009	0.2604	0.2115	1.23	0.22
Constant	1.1029	0.2734	4.03	0.00
Total kgs of hybrid seed planted				
Education	-2.9192	2.9548	-0.99	0.32
Widow	-166.7551	91.5527	-1.82	0.07
Experience	7.6003	3.4340	2.21	0.03
Farm land owned	7.5264	2.0653	3.64	0.00
Asset value	0.0000153	5.00E-06	3.05	0.00
Seed-to-grain price ratio	-187.0041	79.2090	-2.36	0.018
Rainfall stress 2009	-16.6737	85.2510	-0.20	0.845
Constant	327.2199	202.6901	1.61	0.11
Number of obs=1078				
Wald chi 2(7) 50.90				
Prob> Chi2=0.0000				
Log likelihood=-3720.7195				

Source: Authors, based on Tegemeo Institute survey data, 2010

At the same time, the amount of hybrid seed planted by adopters is strongly responsive to the seed-to-grain price ratio. Education no longer matters, but significantly and by a relatively large magnitude (a mean of 167 kgs), women widows plant less hybrid seed. Farm land owned has a positive influence on the amount of hybrid seed planted, as does wealth in livestock, household goods and equipment. Again, rainfall stress has no influence on demand for hybrid seed.

Overall, the regression of seed demand (kgs planted) is better explained in the survey data than is the decision to grow a hybrid—probably because of greater variation and the high proportion of farmers growing hybrids. A likelihood ratio test comparing the value of the log-likelihood functions for probit and truncated regressions (representing the unrestricted, double hurdle) to a tobit regression (the restricted model) favors the double hurdle model statistically at 1% significance. When farmers growing the H611-614D series are excluded (hybrid age=24), the seed-to-grain price ratio has no significance in the probit regression but has the same sign and significance in the second stage. Other variables have the same signs and significance. When adoption rates in Kenya reach their ceiling, economic theory predicts that prices will have no impact on whether a farmer uses maize hybrids, but instead, on the hybrid grown and seed amounts for those who already use them. This suggests that Kenya may be nearing an adoption ceiling in terms of numbers of farmers using maize hybrids. Seasonal variability in whether or not individual farmers grow hybrids may continue to be affected by relative seed and grain prices, given the adoption discontinuities described by Suri (2006).

The hybrid age equation is presented in Table 13. The regression has a very low R-squared but is nevertheless statistically significant. The specification of the regression has no particular basis in economic theory other than as derived from adoption, and results express associations more than a causal relationship.

Table 13: Determinants of Area-Weighted Age of Maize Hybrids Planted in 2009/010

Variable	Coeff	Std. Error	t	P>|t|
Education	0.0186	0.0395	0.47	0.64
Widow	0.8192	0.7184	1.14	0.25
Experience	0.0498	0.0229	2.18	0.03
Farm land owned	-0.0709	0.0320	-2.21	0.03
Asset value	-8.45E-08	3.39E-07	-0.25	0.80
Seed-to-grain price ratio	-1.5986	0.2033	-7.86	0.00
Rainfall stress 2009	-0.4780	1.0897	-0.44	0.66
Constant	27.9062	1.4273	19.55	0.00
Prob > F = 0.0000				
R-squared=0.099				
N=962				

Source: Authors, based on Tegemeo Institute survey data, 2010

Table 13 shows that the larger the farm, the younger is the hybrid planted. Larger, commercially-oriented farmers are able to keep up with the latest releases. The longer the experience of the household head, the older the hybrid he or she grows. Certainly H614 is one of the oldest hybrids, and is grown in zones where farmers have grown hybrids the longest. Notably, when hybrids aged 24 are removed from the regression analysis, there are no changes in statistically significant regressors except that the experience of the household head has a negative sign. Thus, when we exclude farmers growing the H611-614D series, more experienced farmers grow younger hybrids.

An important finding is that the estimated sign on the seed-to-grain price ratio is negative. The higher the seed-to-grain price ratio, the more recently the hybrid grown by farmers has been released. On one hand, this finding is expected. In the continual process of plant breeding, breeders hope to achieve successively higher yields, justifying the research investment and also the cash outlays of farmers. In the worst case, breeders seek to protect past yield gains through improving tolerance of biotic and abiotic stress.

On the other hand, the Tegemeo data indicate that release year is negatively and significantly correlated with yields (rho= -0.044, at 0.01 significance). Combined with regression results, these data suggest that some older releases may continue to show a yield advantage relative to newer releases. At a lower price, farmers would find them to be considerably more profitable (Table 14).

Table 14: Correlation of Maize Yield in Farm Fields with Prices and Year of Variety Release

	Maize yield	
	Correlation	Sig. (2-tailed)
Price (ksh)/kg of seed planted	-.040**	0.0024
Seed to grain price ratio (district mean)	.095**	0.0000
Seed to grain price ratio (farmer-reported)	.082**	0.0000
Year of variety release	-.044**	0.0015

N=2858. Includes major maize field, main season 2004, 2007, 2010
Kendall's tau-b (non-parametric) test of significance

5.0. Conclusions

One of the major contributions of this paper is to demonstrate , using farm-level survey data, that the seed-to-grain price ratio has a significant, strong, and negative effect on farmer demand for hybrid seed, and particularly on the demand for more recently released hybrids, in a maize economy characterized by heterogeneous growing environments and heterogeneous farmers---ranging from subsistence-oriented to fully commercialized growers, the oldest of whom have over 50 years of experience growing hybrids. Generally it is argued that the variation in seed prices is too little to test this hypothesis. Although the data are relatively sparse, the statistical relationship is strong. One reason why, as shown in the data, is the dependence of the seed-to-grain price ratio on agro-ecological zone, the distance to sellers of certified hybrid maize, the number of maize grain traders visiting the village at harvest, and even the latitude and longitude of the household.

The average age of maize hybrids grown in Kenya is old (about 18 years overall in 2010), although the numbers of hybrids planted have increased dramatically and their average age has declined over the past two decades. These are encouraging signs with respect to the progress of maize seed liberalization.

Applying a double hurdle model to explore the factors that influence adoption, we were better able to explain the amount of hybrid seed grown (the intensity of use) than whether or not a farmer chooses to use the seed at all. This outcome is not surprising given the many years of experience with hybrids in Kenya. Rainfall stress is of no importance in either the decision to grow hybrids or how much seed to plant. Women widows are no less likely to plant hybrids than are male households heads, but they plant them on a smaller scale. Factors such as formal education, experience growing hybrids, and farm land owned have long been associated with use of improved seed—and still are. These are robust results and are consistent with the literature.

Tegemeo survey data confirm that Kenya has reached its adoption ceiling years ago in the major maize-producing zones of the country, and is near to doing so in other zones. Instead of expanding the percent of farmers growing maize hybrids, we argue that what matters most today for national maize productivity is the dynamic replacement of older with newer materials, as long as these newer materials truly represent an improvement on previously released hybrids. There is some suggestion in the data that this may not always be the case. Given the strong price-responsiveness demonstrated by these farmers, despite that many remain subsistence-oriented, continued progress in supplying a range of price- (and trait-) differentiated materials in a competitive seed market is important.

Further research will explore related findings using the panel data. Important omitted variables are the characteristics of the hybrids. Estimated effects of agronomic characteristics on adoption may provide useful information for seed companies, as would more complete information on seed sources. A focus on explaining the continued dominance of H614 may also provide insights into what it takes to breed an eminently "successful" maize hybrid in Kenya.

6.0 Policy implications

First, despite increasing numbers of hybrids released to farmers and grown by them over the past few decades, an older hybrid (H614) dominates on farms. Is it that farmers see this hybrid as of superior quality to the more recent releases, or is it that the existence of counterfeit seeds in the market has made many farmers shy away from trying newer varieties to avoid risk of selecting seeds that are not genuine? The recently launched National Seed Policy recognizes the need to counter the challenge of existence of counterfeit seed in the market, and proposes establishment of mechanisms that encourage all registered seed merchants to join seed associations, for purposes of self-regulation to assure distribution of quality seeds.

Secondly, promotion and marketing of new seed varieties has been inadequate due to the cost involved. The existing regulations require seed merchants to appoint agents, sub-agents and stockists who must be licenced by KEPHIS, the seed industry regulator, to distribute and sell their seeds. These requirements have been cited as costly and increase the cost of seed to farmers.

Thirdly, extension and/or information services supplied to farmers have been inadequate. Even with superior seed varieties available at affordable prices, productivity gains are only possible with proper agronomic management. It is noteworthy that the prevailing extension system in the 1980s, the period in which the currently dominant hybrid was released, was the Training & Visit (T& V) system, developed by the World Bank and promoted by national governments. The model was eventually abandoned because of bias in selection of contact farmers, difficulties in demonstrating long-term impact, and financial burden. Nonetheless, in this system, extension providers had close and regular interaction with farmers, providing them with information about the latest technologies, including new seed varieties. The current, demand-driven extension system does not fulfill that need. With insufficient promotion and marketing of new seed varieties, inadequate extension exacerbates the challenge farmers have in accessing information about and taking advantage of new seed.

Finally, despite enforcement of a pan-territorial uniform price for seed by the dominant market player, the KSC, there is evident variation in the seed-to-grain price ratio, which is, as shown here, the strongest determinant of the profitability of growing improved seed in a commercial maize production environment. It continues to be important for policymakers to "get (seed) prices right"—so that more rapid replacement of new, superior seed varieties is observable on farms. Is there a justification for a uniform price?

References

Ariga, J. and T.S. Jayne. 2010. Unlocking the Market: Fertilizer and Maize in Kenya. In *Millions Fed: Proven Successes in Agricultural Development, Chapter 14.* eds. Spielman, D., and R. Pandya-Lorch. International Food Policy Research Institute, Washington, DC

Byerlee D. and C.K. Eicher. 1997. *Africa's Emerging Maize Revolution*. Boulder, CO.: Lynne Rienner Publishers

Byerlee, D. and P.W. Heisey. 1997. Evolution of the African maize economy. In Africa's emerging maize revolution, ed. Eicher, C.K., and D. Byerlee. Boulder, CO: Lynne Rienner

Byerlee, D. and Traxler, G. 1995. National and international research in the post-green revolution period: evolution and impacts, *American Journal of Agricultural Economics* 77, 268–278

Byerlee, D.,M.L. Morris, and M.A. López-Pereira. 1994. Technical Change in Maize Production: A Global Perspective. CIMMYT Economics Working Paper 94-02. Mexico City: International Maize and Wheat Improvement Center (CIMMYT)

Chamberlin, J. and T. S. Jayne. 2009. Has Kenyan Farmers' Access to Markets and Services Imprvoed? Panel Survey Evidence: 1997-2007. Tegemeo Working Paper, Tegemeo Institute, Nairobi, Kenya

De Groote, H., G. Owuor, C. Doss, J. Ouma, L. Muhammad, and K. Danda. 2005. The Maize Green Revolution in Kenya Revisited. Electronic *Journal of Agricultural and Development Economics*, Available online at www.fao.org/es/esa/eJADE 2(1): 32-49

Edmeades, S. 2003. Variety choice and attribute trade-offs within the framework of agricultural houseohldmodels: the case of bananas in Uganda. PhD dissertation , North Carolina State Univeristy, Raleigh, NC

Gerhart, J. 1975. *The Diffusion of Hybrid Maize in Western Kenya*. Mexico City: International Maize and Wheat Improvement Center (CIMMYT).

Gilbert, E., L. C. Phillips, W. Roberts, M. T. Sarch, M. Smale, and A. Stroud. 1993. *Maize Research Impact in Africa: The Obscured Revolution.* Division of Food, Agriculture and Resources Analysis, Office of Analysis, Research and Technical Support, Bureau for Africa. Washington, DC: USAID

Hassan, R. 1998. *Maize Technology Development and Transfer*.CAB International, CIMMYT and KARI, Oxon, UK, Mexico, D.F., and Nairobi, Kenya

Hassan, R. M., M. Mekuria, and W. Mwangi. 2001. Maize breeding research in eastern and southern Africa: Current status and impacts of past investments made by the public and private sectors 1966-1997. Mexico, D.F., CIMMYT

Heisey, P.W., M.L. Morris, D. Byerlee, and M. López-Pereira. 1998. Economics of hybrid maize adoption. In M.L. Morris (ed.), *Maize Seed Industries in Developing Countries*, Lynne Rienner and CIMMYT, Boulder and Mexico, DF

Karanja, D. D. 1996. An economic and institutional analysis of maize research in Kenya. Michigan State University International Development Working Paper No. 57.Department of Agricultural Economics. East Lansing, MI: Michigan State University

KEPHIS. National Crop Variety List. Nairobi, Kenya

Kirimi, L., N. Sitko, T.S. Jayne, F. Karin, M. Muyanga, M. Sheahan, J. Flock, and G. Bor. 2011. A Farm Gate-to-Consumer Value Chain Analysis of Kenya's Maize Marketing System. Tegemeo Working Paper (forthcoming), Tegemeo Institute, Nairobi

Langyintuo, A.S. and C. Mungoma. 2008. The effect of household wealth on the adoption of improved maize varieties in Zambia. Food Policy 33: 550-559.

López-Pereira, M. A. and M.L. Morris. 1994. Impacts of international maize breeding research in the developing world 1966-1990. Mexico City, Mexico, D.F.: CIMMYT

Lynam, J. and R.M. Hassan 1998. A new approach to securing sustained growth in Kenya's maize sector. In *Maize technology development and transfer: A GIS application for research planning in Kenya*, ed. R.M. Hassan. London: CAB International and Overseas Development Institute (CABI)

Magnier, A., Kalaitzandonakes, N. and Miller, D.. 2010. Product Life Cycles and Innovation in the US Seed Corn Industry. Selected Paper prepared for presentation at the Agricultural & Applied Economics Association 2010 AAEA,CAES, & WAEA Joint Annual Meeting, Denver, Colorado, July 25-27, 2010

Meng, E.C.H. 1997. Land allocation decisions and in situ conservation of crop genetic resources: the case of wheat landraces in Turkey. PhD dissertation, University of California at Davis, California

Morris, M.L., J. Risopoulos, and D. Beck. 1999. Genetic Change in Farmer-Recycled Maize Seed: A Review of the Evidence. CIMMYT Economics Working Paper No. 99-07. Mexico, D.F.: CIMMYT.

Nyoro, J., M. Ayieko and J. Songa. 2006. Country Report: Kenya. Program for Africa's Seed Systems (PASS). Mimeo. Tegemeo Institute, Nairobi, Kenya

Ricker-Gilbert, J., T. S. Jayne, and E. Chirwa. 2011. Subsidies and Crowding Out: A Double-Hurdle Model of Fertilizer Demand in Malawi. *American Journal of Agricultural Economics 93*(1): 26-42.

Singh, I., L. Squire, andJ.Strauss (eds).1986. *Agricultural Household Models: Extensions, Applicatoins and Policy*. The World Bank and John Hopkins University Press, Washington, DC, and Baltimore, MD.

Smale, M., and T. S. Jayne. 2010. "Seeds of Success" in Retrospect: Hybrid Maize in Eastern and Southern Africa. In S. Haggblade and P.B.R. Hazell (ed.). *Successes in African Agriculture: Lessons for the Future*. Johns Hopkins University Press for the International Food Policy Research Institute, Baltimore

Smale, M., D. Byerlee and T.S. Jayne. 2011. Maize Revolutions in Sub-Saharan Africa. Policy Research Working Paper 5659. Development Research Group, World Bank, Washington, DC. Maize paper

Smale, M., J. Singh, S. Di Falco and P. Zambrano. 2008. Wheat Breeding, Productivity and Slow Variety Change: Evidence from the Punjab of India after the Green Revolution. *Australian Journal of Agricultural and Resource Economics 6 (52): 419-432*

Suri, T. 2011.Selection and Comparative Advantage in Technology Adoption. Econometrica 79 (1): 159-209

Suri, T. 2006. Selection and Comparative Advantage in Technology Adoption. Center Discussion PaperNo.944, Economic Growth Center, Yale University

Van Dusen, E. 2000. In situ conservation of crop genetic resources in the Mexican Milpa System. PhD thesis, Unviersity of California at Davis, California