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Demand for maize hybrids and hybrid change on smallholder farms in Kenya

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Abstract

Kenya is a globally recognized maize "success story." As the overall percentage of maize farmers growing hybrids tops 80% and the seed industry matures, the slow pace of hybrid replacement on farms, and the continued dominance of the seed industry by Kenya Seed Company, may dampen productivity. Our econometric analysis identifies the factors that explain farmer demand for hybrid seed, and the age of hybrids they grow, considering hybrid seed ownership. Male-headed households with more education, more assets, and more land plant more hybrid seed. Scale of seed demand per farm is differentiated by agroecology. We find a strong farmer response to the seed-to-grain price ratio, which we interpret as evidence of a commercial orientation even on household farms. However, despite the dramatic increase in the number of hybrids sold and the breadth of seed suppliers as seed markets liberalize, an older hybrid still dominates national demand.

JEL classifications: O12, Q12, Q16

Keywords: Kenya; Hybrid maize; Adoption; Seed demand

1. Introduction

Kenya has been touted as global maize "success story" for decades (Byerlee and Eicher, 1997; Gerhart, 1975; Smale and Jayne, 2010). Released just after independence, Kenya's first maize hybrid (H611) was a unique, varietal hybrid with Ecuadorean and Kenyan parentage that diffused "at rates as fast or faster than among farmers in the U.S. Corn Belt during the 1930s–1940s" (Harrison, 1970; Gerhart, 1975, p. 51). Paradoxically, these early gains in maize productivity appear not to have lived up to their potential (De Groote et al., 2005; Karanja, 1996; Lynam and Hassan, 1998). Rates of growth in maize production have fallen behind high rates of growth in the population, leading to a rising import bill (Kirimi et al., 2011).

Numerous explanations have been advanced for stymied progress. For example, 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 (Byerlee and Heisey, 1997; Lynam and Hassan, 1998); economic liberalization probably generated uncertainty; and seed liberalization has been partial, curtailing the availability of improved hybrid seed (De Groote et al., 2005).

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In this article, we focus on one component of the productivity dilemma: the replacement of older by newer hybrids on farms. We posit that it is not adoption of maize hybrids *per se* which determines the effect of hybrid seed on maize productivity in Kenya today, but hybrid turnover. 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). An econometric analysis by Smale et al. (2008) demonstrated that slow change from older to newer improved wheat varieties offset the positive productivity effects of diversifying the genetic base of wheat breeding during the post-Green Revolution period in Punjab, India. To compare Kenya once again with the United States, recent analyses by Magnier et al. (2010) indicated that the average "survival" of a maize hybrid on the seed market was only five years, and the market share of the typical hybrid peaks at two to three years.

To identify the determinants of hybrid demand we estimate a tobit model with correlated random effects (CRE). As proposed by Mundlak (1978) and Chamberlain (1984), the CRE model controls for unobserved heterogeneity and its correlation with observed factors in a nonlinear regression context. To overcome the challenge that the seed-to-grain ratio is observed only for

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farmers who purchase seed and sell grain, we predict the ratio and bootstrap standard errors in the final regressions. We then use ordinary least squares (OLS) regression with robust standard errors to explore the relationship between the average age of maize hybrids grown on farms and demand determinants during the 2009–2010 main growing season.

In this article, we define hybrids as F1 seed purchased from a retailer. This is consistent with the fact that most growers of improved maize seed in Kenya use hybrids, purchasing the seed each year from retailers. Reflecting its history, the practice of recycling hybrids, and of farmer exchange of hybrid seed, is infrequent in Kenya relative to a number of maize-producing countries in Sub-Saharan Africa.

The seed-to-grain price ratio is a major focus of this analysis. To our knowledge, despite its importance in input demand theory, this parameter has rarely been included in seed adoption studies conducted in eastern and southern Africa because pan-territorial pricing policies, parastatal marketing policies, and more recently, various types of subsidies have limited variation at the farm gate. There is no official subsidy on maize hybrids in Kenya. *De facto* liberalization of seed and grain markets has occurred gradually in Kenya since the mid 1990s. Though an incomplete process, it enables us to explore farmer response to variation in the seed-to-grain price ratio.

2. Evidence about demand and supply of maize hybrids in Kenya

2.1. Smallholder use of maize hybrids

Most improved maize seed grown by farmers in Kenya has been hybrid, as compared to improved open-pollinated varieties. Kenyan smallholders generally have a long experience with hybrid seed. 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 a scant 4% had never grown improved maize of any type. Thus, Suri (2011) asserted that given the long experience of farmers with hybrid seed in the major maize-growing zones of Kenya, farmer learning about the performance of hybrids has little to do with whether a farmer chooses to grow a hybrid in any particular year. This is contrary to usual hypotheses in regions where hybrid seed has been more recently introduced. Suri (2011) relates variable adoption among farmers to the heterogeneity of net returns from hybrid use.

Estimates of maize hybrid use by Kenyan smallholders vary depending on measurement approach, year, and survey coverage. In addition to a number of studies undertaken in specific zones of production (e.g., Ouma et al., 2002; Salasya et al., 1998; Wekesa et al., 2002), several in-depth studies based on nationally representative surveys have been conducted. 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%), 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, situated at an intermediate scale in Eastern Province, and are lowest in Nyanza and Coastal Provinces.

Table 1
Percentage of households growing hybrid seed in main season, by agroecological zone, 2009–2010

Agroecological zone	*N*	Maize growers planting hybrids 2009–2010 (%)
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	1,292	82.8

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

Seed industry surveys by CIMMYT (International Maize and Wheat Improvement Center) and KARI (Kenya Agricultural Research Institute), indicated that, based on seed sales, an estimated 62% of maize area was planted to hybrids in 1990 and 1996, and 68% in 2006 (Hassan et al., 2001; Langyintuo et al., 2008; Lopez-Pereira and Morris 1994). Employing data from the CIMMYT/KARI farm surveys, 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, attaining 40% of farmers in the drylands, remaining close to half of farmers in the moist mid-altitude zone, and doubling to 75% of farmers in the coastal lowland tropics. In 2002, two popular hybrids, specifically developed for the coastal area, had recently been released.

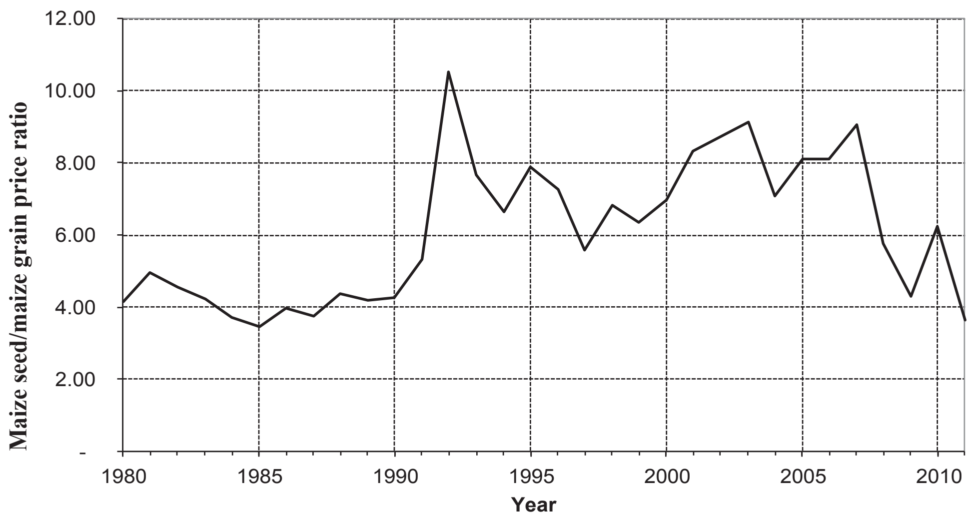
Tegemeo's 2010 survey data (Table 1) provide estimates which are roughly consistent with De Groote et al.'s (2005), except for a farmer use rate of only 40% in the Coastal Lowlands. Other than a low use rate of 61% in the Lower Midland (3–6), rates in all other zones range from nearly 90–100%. Given 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. Farmers surveyed during the 2009–2010 main season planted up to six maize fields with hybrids, but most grow only one hybrid.

Survey data collected by Tegemeo and CIMMYT/KARI also reveal the old age of modern varieties (years since release) grown by Kenyan smallholders. Hassan (1998) found that the area-weighted average age of all modern varieties (improved open-pollinated and hybrids) grown by farmers was 23 years. For comparative purposes, in this table only, we have combined both hybrids and modern varieties in the Tegemeo data. Over 95% of maize plots were planted to hybrids.

Table 2
Age of modern maize hybrids and varieties grown by farmers, by agroecological zone and year, main season

Agroecological zone	Average age 2004	Average age 2007	Average age 2010	Average age All years		Area-weighted average age 2004	Area-weighted average age 2007	Area-weighted average age 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: Authors, based on Tegemeo Institute panel survey data, 2004–2010.
Only 4.4% are improved open-pollinated varieties; 95.6 are maize hybrids, of 3,330 total seed lots planted. Differences within groups (a, b, c) are not statistically significant, but are significant between groups. Variety names not recorded in 2000 or 1997.



Source: Hugo De Groote, International Maize and Wheat Improvement Center.

Fig. 1. Seed-to-grain price ratios in Kenya, 1980 to 2011.

The Tegemeo data suggest that the area-weighted average age of modern maize varieties dropped substantially during the 2000s relative to the time period of Hassan's study (Table 2). In all zones taken together, average ages are 16.5–18 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. For purposes of comparison, a recent study by Swanckaert (2012) documents area-weighted average ages of 15 (2001) and 16 (2010) based on the CIMMYT/KARI surveys.

H614D, released in 1986 based on earlier versions, represented 55% of all modern maize plots planted by farmers surveyed by Tegemeo in 2004, 44% in 2007, and 43% in 2010. Hassan (1998) reported that H614 accounted for 41% of seed sales in 1987, and over half of sales from 1988 through 1991. The genetic base of H614, like all "Kitale hybrids," is two populations which were continuously improved through recurrent reciprocal selection (Njoroge et al., 1992). The first was an OPV (Kenya Flat White) that was originally selected from farmers' local materials (mixtures of landraces from multiple sources). The second was an Ecuadorian landrace imported in 1959 by Kenya's first maize breeder (Harrison, 1970). Maize breeders explain the longevity and dominance of H614 by the fact that it is uniquely suited to the growing conditions of the Kenyan highlands, which are also unique by world standards (late-maturing, wet highland tropics). The maturity period of H614 is extremely long and its range is wide (180–270 days). Among varieties grown by Tegemeo's sample farmers in 2010, its yield potential is surpassed only by more recent hybrids produced by Kenya Seed Company (KSC).

2.2. Evolution of hybrid seed supply

The KSC was established by European settlers in 1956. From 1963 onwards, the Kenyan government mandated KSC to produce the seed of the new maize varieties. The Kenyan government obtained a majority share through the Agricultural Development Corporation, but the company kept its commercial nature. In response to pressure exerted by the World Bank and other donors, market liberalization began in Kenya during the early 1980s. Given the centrality of maize to food security in the country and its political important, controls were not lifted in the maize grain market, and the national produce board was not formally restructured, until 1995. Gradually, the seed sector has expanded to permit the entry of private companies, including national, regional and multinational companies. Nonetheless, nearly 20 years later, the Kenyan seed market is still heavily dominated by the KSC, a national parastatal.

There is some evidence that liberalization has led to entry of new seed companies in the maize market. In her thesis, Swanckaert (2012) reports that while KSC was the only maize seed company prior to 1992, currently there are 11 companies with varieties registered to their names. The CIMMYT/KARI surveys identified only varieties from KSC in 1992. By 2001, farmers reported the use of seed produced by five new maize seed companies. These included two national, private companies (Lagrotech and Western Seed Company), two multinationals (Monsanto and Pioneer), and one regional company (Pannar from South Africa). By 2010, farmers were planting maize seed marketed by two more local private companies (Faida Seeds and Freshco), and one regional company (Seedco from Zimbabwe).

Official releases of improved maize varieties and hybrids have proliferated. Currently, the plant variety registry of the Kenya Plant Health Inspectorate (KEPHIS) lists 164 varieties released from 1964 up to 2009. Through 1989, only 14 varieties were registered, and these were publicly bred materials owned by either KARI/KSC or KSC/KARI; the first fully privately owned variety was PAN 5195, registered in 1995 (Swanckaert, 2012). Thereafter, KSC and KARI began registering maize varieties under their own names. Swanckaert (2012) reports that 85% of Kenya's maize varieties have been registered since 2000.

The numbers of improved maize varieties and hybrids grown on farms has also increased tremendously. Hassan (1998) found only 12 hybrids grown by farmers in 1992, and all had been released and were owned by KARI/KSC. Tegemeo data indicate that the number of hybrids on farms was 33 in 2004 to 50 in 2010. Swanckaert notes that new maize materials resulted from investments in private breeding as well as public breeding programs by different KARI research stations. Half of the maize varieties reported by farmers in 2010 were distributed by KSC, but included those developed by KARI as well as KSC breeding programs. Meanwhile, new national companies began by distributing publicly bred maize materials, later supplementing these with materials from their own, privately funded research programs.

Despite these changes, Swanckaert (2012) concludes that although competition in the seed market has intensified, the impact of new seed companies on market concentration has been smaller than expected. The number of private companies that have been able to establish a market niche are few. In fact, even KSC has had some difficulty replacing its older varieties with new releases. Tegemeo's 2010 survey data reveal that 83% of all hybrid growers planted seed owned by KSC in the main season. The remaining 17% planted at least some seed from other companies, including, in order of greater frequency, Western Seed, Pioneer, Monsanto, Pannar, Agriseed, Lagrotech, and Faida.

Key informant interviews conducted by the authors with industry representatives from KSC, Western Seed, maize seed retailers, and a farmer group in Western Kenya during November of 2012 provide some additional insights into the current situation in that region of the country. First, in addition to the factors cited in the introduction, key informants report that H614 continues to dominate in the highlands because of its ability to withstand moisture stress relative to other hybrids, the resistance of its flintier grain to grain borers and weevil damage, heavier grains, and preferences for its grain when roasted or prepared as *ugali*. Preferences for these attributes, and the long-term, demonstrated popularity of H614 in the market, have made farmers reluctant to switch to newer varieties despite possible yield advantages. Attributes other than yield *per se* continue to feature in the seed choices of Kenyan farmers, like those of smallholder farmers in other developing agricultural economies (e.g., for maize in Malawi, Smale et al., 1995 and more recently, Lunduka et al., 2012; for wheat in Turkey, Meng, 1997; for bananas in Uganda, Edmeades, 2003).

Second, informants claim that the disjoint between local demand and supply of preferred hybrids persists, and farmers are hesitant to use less preferred seed. Inadequate supply of preferred varieties has also resulted in production of counterfeit seeds, which are packaged to look like the preferred variety and sold locally. Farmers have fallen prey to this practice, which has been common in the highland altitudes where the H614 is the most preferred variety. The use of packaging materials that are easily copied enables counterfeiters to package fake seeds. Also, lack of proper enforcement of regulations and less severe penalties prescribed by law have encouraged existence and distribution of counterfeit seeds. The National Seed Policy of Kenya explicitly recognizes this problem (Republic of Kenya, 2010).

According to key informants, some companies have provided incentives to distributors by permitting higher sales margins in order to encourage sales of less preferred hybrids. Distributors then withhold the most preferred hybrids in order to advertise other varieties with higher margins first. This practice is especially common in mid altitude zones where several seed companies have well-adapted hybrids.

Table 3
Maize seed-to-grain price, by seed type and year

		Farmer seed price/ district grain price	Farmer seed price/ farmer grain sales price
2004	*N*	1,107	395
	mean	10.36	10.73
	Std. dev.	1.42	3.61
2007	*N*	1,432	475
	mean	10.97	11.51
	Std. dev.	2.64	5.27
2010	*N*	1,624	396
	mean	6.70	7.09
	Std. dev.	1.73	3.65

Source: Authors, based on Tegemeo Institute panel survey data, 2004–2010.

From the perspective of smallholder farmers, there are historical grounds to believe that high seed costs continue to hinder use of hybrid maize. Seed development and production involves a long and expensive process, and distribution to Kenya's scattered, small-scale growers is costly. The next section discusses price incentives in greater detail.

2.3. Price incentives

Economic theory predicts that the seed-to-grain price ratio (input cost to output price) 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.

The ratio of the KSC price for maize seed to the official maize price (both in nominal terms) is shown in Fig. 1, from 1980 to 2011. The sharp peak in the ratio in the early 1990s is visible, as is the gradual decline in the price through 2010, when the ratio fell from 6.26 to 3.65. Data include only official, national prices for KSC varieties.

Seed-to-grain price ratios on farms, as calculated based on the district median grain price and prices reported by farmers who purchased seed and sold grain, are reported in Table 3 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. Mean ratios for hybrids appear to drop in 2010 relative to the previous two survey years, when means were 10–11 in magnitude. 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.

Ratios changed substantially between 2007 and 2010 favorably for hybrid maize growers. Estimates from the Tegemeo data show a very large increase in the maize grain price in 2010 relative to the seed price. 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, contributing to the observed increase in maize prices.

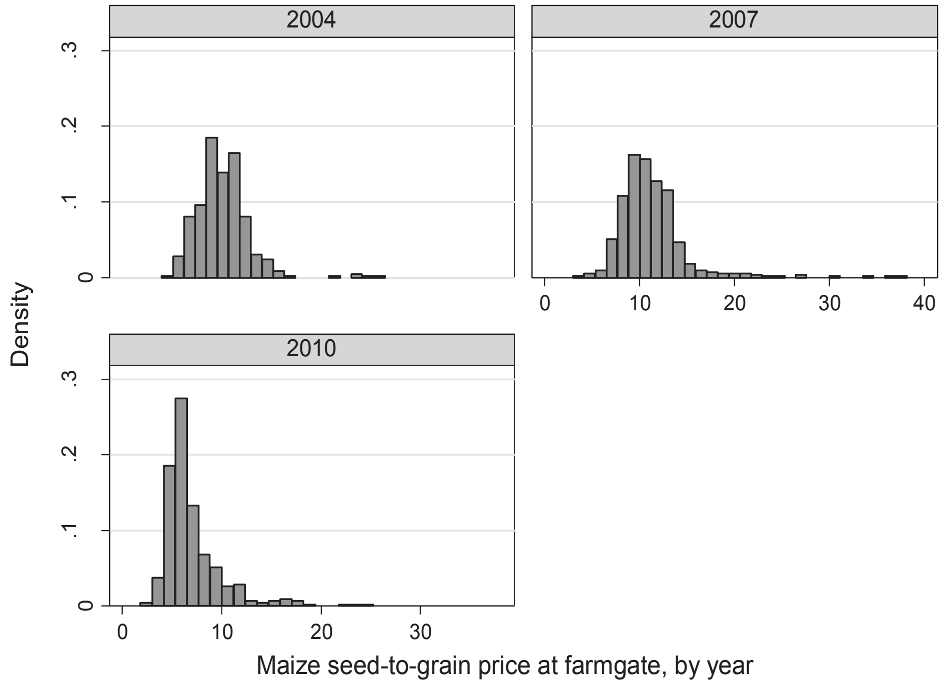
Heisey et al. (1998) provide some useful interpretation of the magnitude of seed-to-grain price ratios, based on break-even yield gain curves constructed by Byerlee et al. (1994), to illustrate the expected profitability of hybrid maize for smallholder farmers. At a low seed-to-grain price ratio of 5:1, 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 25:1–30:1. This pattern occurred in the United States, 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.

Figure 2 shows the overall distribution of farm-gate seed-to-grain price ratios, by year. Most price ratios are concentrated around 5:1 in 2010, the mode having shifted downward from around 10:1 in the preceding survey years. Consistent with Heisey et al.'s (1998) overall characterization of the global hybrid seed industry, only the skewed tails of seed-to-grain price distribution observed at the farm gate are above 20:1. Thus, according to Figs. 1 and 2 and Table 3, seed-to-grain price ratios based on official data series (KSC seed only) have followed a fairly profitable path for hybrid seed use by smallholders.[1]

There is no national subsidy scheme for maize hybrids in Kenya. KSC still recommends, but does not impose retail prices for its seed. Most of the variation in KSC seed costs per kilogram at the farm-gate reflects factors such as transactions and transport costs. However, official seed prices also vary by company. Regression of the kg-weighted average seed prices paid by hybrid growers indicates that trader densities (and not distance to market), distance to the NCPB outlet, hybrid age, and agroecological zone (AEZ) are statistically significant in explaining variation (Table 4). KSC hybrids (such as H614), which are older, have lower prices. The data confirm that hybrid age and KSC ownership are significantly correlated. Both hybrid age and KSC ownership are also correlated with yield potential and maturity class, which are the only major traits for which we have information for all hybrids. Substituting a dummy variable measuring KSC seed ownership for hybrid age confirms that KSC is significantly cheaper (Table 4).[2]

[1] For purposes of comparison, means for local maize were 0.35 ($n = 285$) in 2004, 0.59 ($n = 141$) in 2007, and 0.64 ($n = 71$) in 2010.

[2] Farmer group membership had no significant impact on prices paid by farmers for maize seed, because seed purchases are not usually made through groups in Kenya.



Source: Authors, based on Tegemeo survey data, 2004–2010.

Fig. 2. Maize seed-to-grain price ratios at the farm gate, by survey year.

Table 4
Determinants of hybrid seed prices paid by farmers in 2009–2010 main season

	Coef.	Std. err.	$P > t$		Coef.	Std. err.	$P > t$
Coastal Lowland	10.32	5.57	0.0640	Coastal Lowland	10.34	4.96	0.0370
Lowland	15.49	5.16	0.0030	Lowland	8.97	4.61	0.0520
Lower Midland (3–6)	38.88	4.08	0.0000	Lower Midland (3–6)	24.94	3.73	0.0000
Lower Midland (1–2)	14.03	4.05	0.0010	Lower Midland (1–2)	4.30	3.64	0.2370
Upper Midland (2–6)	16.80	3.86	0.0000	Upper Midland (2–6)	9.03	3.46	0.0090
Upper Midland (0–1)	14.67	3.92	0.0000	Upper Midland (0–1)	9.56	3.48	0.0060
Lower Highland	7.23	3.84	0.0600	Lower Highland	3.99	3.41	0.2420
Km to nearest market	0.0703	0.1993	0.7240	Km to nearest market	0.0406	0.1772	0.8190
Number of traders in village	−0.3881	0.0830	0.0000	Number of traders in village	−0.2359	0.0745	0.0020
Km to nearest NCPB outlet	0.1060	0.0408	0.0100	Km to nearest NCPB outlet	0.0735	0.0363	0.0430
Area-weighted hybrid age	−0.7444	0.0880	0.0000	All KSC seed	−34.0727	1.8290	0.0000
Constant	131.02	4.14	0.0000	Constant	152.44	3.88	0.0000
$N = 998$				$N = 998$			
R^2	0.29			R^2	0.43		
$F(11, 986)$	35.91			$F(11, 986)$	68.62		
Prob > F	0.0000			Prob > F	0.0000		

Source: Authors.

3. Econometric methods

3.1. Conceptual framework

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 et al., 1986).

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 seed 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 about hybrid performance, and yield 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, geographical region, national income per capita, average farm size, and proxies for the development of road and input infrastructure.

Table 5
Definition of variables

Conceptual variable	Operational variable	Mean	St. dev.
Dependent			
Scale of hybrid use	Total kilograms of F1 hybrid maize seed planted	11.71	27.86
Slowness of hybrid change	Area-weighted average age of maize hybrids planted in 2009 main season. Age = 2010-release year	18.38	8.69
Independent			
Seed-to-grain price ratio	Ratio of village median seed price to village median grain price paid by farmers (KSh)	10.41	2.70
Education	Formal educational attainment of adults in household (years)	7.28	2.97
Female head	Recognized head of household is a female = 1, 0 otherwise	.21	.40
Young adults	Number of adults 15–24 years of age	1.93	1.60
Mature adults	Number of adults 25–64 years of age	2.19	1.29
Farm land owned	Total acres owned in previous survey year	6.01	9.00
Total value of assets (mill KES)	Value of all farm physical and livestock enumerated in previous survey year (natural log)	257,766	438,002
Seed access	Distance to nearest seller of certified maize seed	4.24	6.41
Rainfall	Total mm of rainfall in major season	573.65	265.11
Agroecological zone	Dummy variables for seven out of eight agro-ecological zones, excluding the Coastal Lowlands	NA	NA

Source: Authors.

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 conform to a decision-making model based entirely on profit maximization. Of the farmers who planted maize in 2010, only 28% overall sold maize.

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 et al., 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 (2003). Expressed in terms of kilograms (kg) of hybrid seed, these constrained choices are input demand equations, including the choice of "zero" kilograms as a lower bound.

In the framework of the household farm, implicit prices 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 explicit seed and grain prices. The observed ratio of seed-to-grain prices itself depends on physical market infrastructure and the variety grown, and whether or not there are premia paid for grain of a certain quality.

In reduced form, the demand for maize seed can be expressed as a function of sociodemographic characteristics (Ω_h), farm physical characteristics (Ω_f), and market characteristics (Ω_m) as well as exogenous income (I^0), land area (L), and market prices for seed and grain (p_s, p_m). The conceptual framework for estimating seed demand can be expressed as in Eq. (1):

$$s = s(\Omega_h, \Omega_f, \Omega_m, I^0, L, p_s, p_m). \quad (1)$$

We model seed demand (s) in terms of the scale of hybrid seed use on the farm (total kilograms of hybrid seed planted, including zero) and the average age of the hybrids planted on the farm.

3.2. Data

The data were collected by the Tegemeo Institute of the Egerton University (Kenya). The surveys were implemented in the 1999/2000, 2003/2004, 2006/2007, and 2009/2010 cropping years. The sampling frame was prepared in consultation with the Kenya National Bureau of Statistics (KNBS) in 1997. Census data were used to identify all nonurban divisions in the country, and these were allocated to AEZs. Divisions were selected from each AEZ proportional to the size of population. Fourth, within each division, villages and households were randomly selected from a list frame. A total of 1,578 households were selected in 24 districts within seven agriculturally oriented provinces of the country. The sample excluded large farms with over 50 acres and two pastoral areas. After considering the initial exclusion of sample households in Turkana and Garissa districts because they were not representative of agricultural areas, the attrition rate has been 13%.

An initial survey was conducted in 1997, with a much more restricted survey instrument than those applied in later years. Later years include detailed modules about the changing demography of the household, agricultural production and marketing infrastructure, as well as complete information on farm and non-farm income sources and assets. However, seed price information was not obtained until the 2004 survey. We use data collected in years 2003/2004, 2006/2007, and 2009/2010 in the econometric model.

3.3. Econometric approach

Fixed effect estimators applied to panel data are inconsistent or biased in the case of nonlinear models such as the Tobit,

Table 6
Tobit CRE model explaining demand for hybrid maize seed (kg) by smallholder farmers in Kenya, 2004–2010

	APE (SE)
Female head	−1.784*
	(1.010)
Education	0.262
	(0.296)
Young adults	0.346
	(0.425)
Mature adults	0.489
	(0.534)
Farm land owned	0.542***
	(0.128)
Asset value	1.592***
	(0.608)
Rainfall	0.0156***
	(0.00333)
2007	5.679***
	(1.043)
2010	10.55***
	(1.896)
Seed-to-grain price ratio	−0.343***
	(0.0901)
Seed access	−0.293
	(0.185)
Lowland	11.89***
	(3.995)
Lower midland (3–6)	−0.201
	(3.055)
Lower midland (1–2)	7.978***
	(3.036)
Upper midland (2–6)	19.05***
	(3.493)
Upper midland (0–1)	11.85***
	(3.150)
Lower highland	10.91***
	(3.088)
Upper highland	20.95***
	(3.497)
	(0.330)
Constant	−60.88***
	(11.44)
Observations	3,051
$F(23, 3{,}028) = 24.12$, Prob > $F = 0.0000$	
Log pseudo-likelihood = −11,383.952	

Source: Authors, based on Tegemeo Institute survey data.
Note: Robust standard errors in parentheses *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Coefficients of means of time-varying variables not shown.

probit, and truncated regressions (Wooldridge, 2010). To handle this challenge with longitudinal data, we estimate our regressions with year effects and also with the Mundlak-Chamberlin device (Chamberlain, 1984; Mundlak 1978). The CRE model, or Mundlak-Chamberlin device, controls for the correlation between unobserved, time-constant heterogeneity and observed factors in the nonlinear regression model by introducing the means of time-varying variables.

Seed costs per kilogram at the farm gate are observed only for farmers who purchase seed, most of which is hybrid maize—even though all farmers face prices. One solution to this problem is to predict unobserved values of the seed-to-grain price ratio using fixed effects for district, AEZ, year, and other household characteristics that are related to market participation but are not included in the seed demand equation. This approach has the benefit that the predicted value reflects some of the underlying heterogeneity in the farm population. The disadvantage of the approach is that using a generated variable in place of an observed variable introduces measurement error which may be correlated with the dependent variable. Standard errors on coefficients need to be bootstrapped based on the joint estimation. We tested predicted ratio as well as an imputed ratio. To impute the ratio, we applied the ratio of the village median farm-gate seed price to the village median farm-gate grain price to missing data points. The magnitudes of estimated coefficients in the seed demand equations did not differ appreciably, with the exception that the coefficient on seed access was not statistically significant when prices were imputed but was when they were predicted with a regression. Given the inherent limitations associated with the generated variable, we chose to use the imputed ratio.

The hybrid age regression was estimated with OLS applied to a single year of data. 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), the regression was also estimated without the 24 year peak to ascertain whether it remained relevant for other observations. Logarithmic transformation of the dependent variable smoothed the values.

3.4. Variables

Dependent and explanatory variables are defined in Table 5, following Eq. (1).

In the Tegemeo data, a household grows a maize hybrid if a hybrid is named and the seed is purchased from a retailer. Seed demand is defined as the total kilograms of hybrid seed planted, with a lower limit of zero. By a hybrid's "age" we mean the number of years the hybrid has been grown since its initial year of introduction, or the current year minus the release year. Since farmers may grow more than one hybrid, we weight the age of each hybrid grown by the proportion of total hybrid acreage planted, and compute the acreage-weighted average age. In those cases, seed prices are also weighted by the amount purchased of each hybrid.

Household characteristics include the average educational level of all adults in the household in years, which we hypothesize to be positively related to hybrid seed demand, and whether the recognized head of the household is male or female. Over four-fifths of female heads of households in the sample are widows, and we know that widows generally have less access to productive resources and their households are missing one important adult decision-maker and worker. Thus, we expect female headship to be negatively related to demand for hybrid

Table 7
Determinants of area-weighted age of maize hybrids planted in 2009/2010

	Coef.	Std. err.	t	$P > t$	Coef.	Std. err.	t	$P > t$
KSC seed	0.919	0.038	24.330	0.000				
Seed-to-grain price ratio					−0.007	0.001	−10.620	0.000
Female head	0.093	0.034	2.750	0.006	0.080	0.042	1.930	0.054
Education	0.001	0.002	0.290	0.770	0.001	0.002	0.580	0.561
Young adults	−0.018	0.009	−1.990	0.047	−0.020	0.011	−1.830	0.068
Mature adults	0.014	0.011	1.270	0.206	0.016	0.014	1.170	0.242
Farm size	−0.002	0.002	−1.190	0.235	−0.002	0.002	−1.230	0.220
Assets (mill)	0.002	0.000	0.070	0.947	−0.016	0.000	−0.450	0.656
Seed access	−0.002	0.003	−0.740	0.459	−0.003	0.003	−0.750	0.452
Lowland	−0.123	0.112	−1.100	0.273	−0.242	0.137	−1.770	0.077
Lower midland (3–6)	0.022	0.089	0.250	0.801	−0.223	0.108	−2.060	0.040
Lower midland (1–2)	0.097	0.088	1.100	0.271	−0.088	0.105	−0.830	0.404
Upper midland (2–6)	0.007	0.085	0.080	0.933	−0.162	0.102	−1.590	0.113
Upper midland (0–1)	0.124	0.085	1.450	0.148	0.065	0.103	0.630	0.526
Lower highland	0.126	0.084	1.490	0.136	0.070	0.101	0.690	0.488
Upper highland	−0.167	0.103	−1.620	0.106	−0.246	0.124	−1.990	0.047
R^2	0.451				0.218			
Prob > F	0.000				0.000			

Source: Authors.
Notes: $N = 941$. Dependent variable is expressed in natural logarithm.

seed. The age of the household head, which is highly correlated with educational level and demographic composition of the household, is not included. To ensure exogeneity, we include numbers of economically active household members by age group (young adults, mature adults). These variables are indicators of the household labor supply, and other factors held constant, we would expect them to relative positively to growing hybrid maize seed. Farm and household capital include land owned and total current value of all farm physical and livestock assets enumerated, lagged one survey year. In place of "exogenous" income in the single-period model of the household farm, we use assets as an indicator of income-generating capacity, "permanent," or "exogenous" income. Because receipt of cash credit, a financial asset, is potentially endogenous with the decision to grow hybrid seed, we considered including its predicted value. However, we found that cash credit received 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 do not include the variable. We hypothesize that all asset variables are positively associated with the use and scale of use of maize hybrids in Kenya.

The seed-to-grain price ratio is our robust measure of market characteristics and relevant prices, but we also include access to hybrid seed, indicated by the distance to the nearest seller of certified maize. We expect demand for seed of maize hybrids to relate negatively to both of these market parameters. To control for farm physical factors and maize-growing potential, we use dummy variables for AEZ as well as total rainfall in the major growing season. With the exception of the Lower Midland (3–6) zone, hybrid maize use generally increases with altitude in Kenya, as evidenced by the data shown in Table 1. Taking AEZ into account, we hypothesize that better rainfall positively affects the use of hybrid maize seed.

4. Regression results

Table 6 shows the average partial (marginal) effects estimated with the Tobit CRE model of hybrid seed demand. Coefficients on the means of household time-varying variables, which mimic a fixed effects statistical model, are not included.

Female headship reduces the scale of hybrid seed use significantly, but by a small amount of 1.8 kg on average, when other factors have been considered. Neither labor quality (education of adults in the household) nor labor supply (the numbers of adults) appears to influence the amount of hybrid seed planted among smallholder maize growers. Variation in these variables is not high among years, and inclusion of their household means across years removes the significance of labor supply. Otherwise, the numbers of both young and mature adults have positive effects on the amount of hybrid seed planted. Similarly, farm size bears the expected positive and significant relationship to the scale of seed demand, but the magnitude is not large, given that most households pursue other productive activities. The magnitude of the estimated effect of the total value of household assets is relatively large, however. The seed-to-grain price ratio is also a highly significant factor, and is negatively related to hybrid use, as predicted by theory. The higher the prices paid for seed relative to grain on farms, the less hybrid seed is demanded. The effect is relatively large in magnitude. Roughly consistent with the data shown in Table 1, all dummies for AEZ are statistically significant relative to the Coastal Lowlands in Table 6, with the exception of the Lower midland 3–6 zone. Magnitudes of coefficients vary, but generally rise with elevation, although the coefficient is also quite large in the Lowlands relative to the Coastal Lowlands. Even considering agroecology, rainfall is also a positive and significant predictor of the amount of hybrid seed planted by smallholder maize growers in Kenya.

Table 8
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	−0.040	0.0024
Seed-to-grain price ratio (district mean)	0.095	0.0000
Seed-to-grain price ratio (farmer-reported)	0.082	0.0000
Year of variety release	−0.044	0.0015

Source: Authors.
Notes: $N = 2{,}858$. Includes major maize field, main season 2004, 2007, 2010. Kendall's tau-b (nonparametric) test of significance.

The hybrid age equation is presented in Table 7, with the KSC seed ownership and the predicted seed-to-grain price ratio included interchangeably given their significant correlation. The R^2 is relatively high for a regression of this type, although it is much higher when the KSC seed ownership variable is used as compared to the seed-to-grain price ratio (46% as compared to 22%). KSC seed is strongly associated with older hybrids planted, as is female headship. Younger adults are negatively associated with the average age of the hybrid seed planted, perhaps as a reflecting an earlier life-cycle stage of the household. Descriptive statistics indicate that 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.

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 data shown in Table 8 indicate that release year is negatively and significantly correlated with yields ($\rho = -0.044$, at 0.01 significance). Combined with regression results shown in Table 7, this suggests that some older releases may continue to show a yield advantage relative to newer releases. Many older varieties are late-maturing, which is associated with higher yields under favorable conditions. At a lower price, farmers would find them to be considerably more profitable. Still, our finding suggests that the yield advantage of newer materials just may not be as discernible to farmers as hoped. Traits other than yield potential (resistance, drought-tolerance, fodder yield) are, of course, important—particularly in Kenya's varied agroecologies. Although we would have preferred to test the effects of traits, only maturity and yield potential were available for all hybrids grown, and these traits are highly correlated with whether or not the owner of the seed is KSC (e.g., later-maturing, higher yield potential hybrids grown in higher altitudes).

5. Conclusions

In this article, we have (a) documented adoption rates over time, (b) estimated the demand for hybrid seed among smallholder farmers, and (c) tested the responsiveness of demand to seed-to-grain price ratios. A contribution of this article is to demonstrate that, consistent with economic theory, the seed-to-grain price ratio at the farm-gate has a significant, strong, and negative association with farmer demand for hybrid seed, and particularly on the demand for more recently released hybrids. This finding pertains in a maize economy characterized by heterogeneous growing environments and heterogeneous farmers—ranging from subsistence-oriented to fully commercialized growers. Generally it is argued that the variation in seed prices is inadequate to test this hypothesis. Although the data are relatively sparse, the distributions make economic sense and the statistical relationship is strong in the multivariate regressions we estimate.

In order to apply a nonlinear Tobit model to panel data, we use the Mundlak-Chamberlin device, which controls for the correlation between unobserved, time-constant heterogeneity and observed factors in the nonlinear regression model by introducing the means of time-varying variables. Factors such farmland owned, and the value of assets have long been associated with use of improved seed—and still differentiate among smallholder maize growers in Kenya. Female headship diminished the scale of hybrid seed planted, even when controlling for assets and the land owned. Formal education does not appear to play a major role in demand for hybrid seed. This finding is not surprising given that farmers in Kenya have known about hybrid maize, and most have used it at one time or another, if not continuously, for many years. The significant of household labor supply depends on whether we control for time-variation or not; limited variation in this factor may explain its lack of significance when means that vary among households but not across years within individual households are included. Finally, as is well known in Kenya, adoption, and the scale of hybrid seed use per farm, is highly differentiated by AEZ. These are robust results and are consistent with the literature.

6. Policy implications

Data on smallholder use of maize hybrids, collected by Tegemeo Institute, confirm that Kenya has achieved progress in liberalizing maize seed markets and that adoption rates are nearing or at their ceiling in the zones most favored for maize production. Much more is needed, however, for Kenya's maize growers to succeed in reaching their productivity potential.

Findings confirm that maize-growing farmers who grow less hybrid seed are relatively disadvantaged with respect to education, land and assets, and more likely to be headed by women. This result has clear policy implications concerning the need to target certain groups in order to expand use of maize hybrids and reduce inequities in rural Kenya.

However, beyond expanding hybrid use, 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 price-responsiveness demonstrated by these farmers, despite that most remain subsistence-oriented, continued progress in supplying a range of price- (and trait-) differentiated materials in a competitive seed market is important. Key informant interviews highlighted that effective demand for hybrid maize seed is still constrained by informational and marketing constraints.

Despite increasing numbers of hybrids released to and grown by farmers over the past few decades, an older hybrid (H614) dominates on farms. H614 is both a unique hybrid and a hybrid that is uniquely suited to the Kenyan highlands. The seed of H614, and other hybrids owned by KSC, is generally cheaper. Evidence presented here also suggests that the yield advantages of new releases on smallholder farms may not be as superior as expected, although this hypothesis requires further testing.

Is it that farmers see older hybrids 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? Some observers suggest that counterfeiters target KSC seed more than non-KSC seed. The recently launched National Seed Policy (Republic of Kenya, 2010) recognizes the need to eliminate 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.

Promotion and marketing of new seed varieties has been inadequate due to the cost involved. The existing regulations require seed merchants to appoint agents, subagents and stockists who must be licensed by KEPHIS (National Crop Variety List, Nairobi, Kenya), the seed industry regulator, to distribute and sell their seeds. These requirements have been cited as costly, driving up the cost of seed supplied to farmers.

Finally, regressions findings underscore that in Kenya's liberalizing seed market, where smallholders are commercializing, maize growers are responsive to seed prices. Seed price policy is important; "getting (seed) prices right" could speed the replacement of old hybrids by newer, superior hybrids. For example, is there a justification for KSC to continue encouraging uniform prices among its hybrids? In fact, do the advantages of newer releases supplied by other companies justify charging higher seed prices?

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