The role of maize varietal development on yields in Kenya

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Abstract:

Since the start of seed and other market reforms in the 1990s, the annual number of improved varietal releases for maize in Kenya has increased substantially. Reforms have resulted in not only private firms entering the market and releasing improved varieties, but also an increase in varietal releases by the public sector. This paper reviews some of the key policy reforms related to maize in Kenya, their impacts on varietal development and yields.We present a yield model to relate national maize yields with a number of exogenous factors, that have policy oriented effects associated with significant impact on yields. We use a number of policy variables such as public R&D, the number of Plant Breeder's Rights issued, and the years since private varieties have been introduced as instrument variables that influence new varietal releases directly, and yields indirectly. We find that the number of improved maize varieties released and the share of area under improved varieties have no impact on maize yields. We argue that this is because farmers continue to use older improved varieties, and that newer improved varieties may not have the assumed yield advantage and/or are not as widely adopted to have the desired yield impact.

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1 Introduction

Raising productivity is essential to sustain economic and income growth. In turn, technical change is the main driver of increased productivity, underlining the ongoing importance of focusing on technology as a primary change agent. The experience of industrialized countries confirms this insight where empirical findings consistently show that technical advances have been the main contributor to growth. This has also been the case within agriculture where rapid increases in productivity was often due to the adoption of specific technologies--such as hybrid maize, genetically modified crops, mechanization and the use of chemical inputs.

Despite the recognition that technology is important for growth, it remains under-utilized in many countries, particularly in sub-Saharan Africa (SSA). Modern input use remains low, exemplified by the low rates of fertilizers application. For SSA, fertilizer use intensity averaged less than 16 kg/ha of arable land in 2014, whereas it was 160, 345 and 130 kg/ha for South Asia, East Asia and Latin America, respectively (FAO, 2016). The use of improved seed varieties (IV)--a key ingredient to the success of the Asian Green Revolution--is also low accounting for 35% of all food crops grown in SSA in 2010 (Walker & Alwang, 2015).

The low use of farm inputs in SSA is at odds with the considerable farm level evidence that shows farmers in SSA benefit when they use improved varieties, especially for maize (see Doss et al. (2003) for synthesis and Nyangena and Juma (2014), Gitonga and De Groote (2016), Muraoka et al. (2016), Mathenge, Smale, and Olwande (2014) for recent studies on farm level impacts of adopting improved maize varieties in Kenya). Studies of cross-country adoption and yield data also suggest a positive association between the two (Evenson & Gollin, 2003; Renkow & Byerlee, 2010; Fuglie & Marder, 2015). Evenson and Gollin (2003) estimate that 88% of the cereal yield growth in Asia between 1960-1986 was due to crop genetic improvement and the use of IVs, but only 28% for SSA reflecting the limited role that IVs have played in yield growth in SSA. Increasing the adoption of modern inputs is therefore considered an important policy goal.

There are many reasons for the low use of modern inputs and technology in African agriculture and significant differences exist across and even within countries (Sheahan & Barrett, 2017). Ultimately the non-adoption of productivity improving technologies rests on a combination of economic (the technology is not profitable), institutional (regulatory barriers and poor governance may limit availability) and social constraints.

Policy--or lack thereof--can also be an important determinant of technology adoption. Providing subsidies and other incentives are the most direct ways that governments encourage adoption. More subtle are policies related to market competition and innovation that can lower prices and increase choices for farmers to suit their specific economy and agro-ecological needs.

Whether a given a policy or a set of policies have the desired outcome or not is an empirical question and the focus of this study. Specifically our interest is to understand the role that policy changes have had on the supply of improved maize varieties in Kenya. In particular we examine whether market friendly policies designed to encourage private sector participation in Kenya's seed sector have contributed to the improvements in maize productivity. Since the late 1990's, Kenya's market reforms have resulted in the entry of a number of private firms in the maize seed market and a marked increase in the number of IV that have been released (Swanckaert, 2012). As we show in the following sections, of the 354 IV of maize released between 1964 and 2015, 333 (94%) were introduced after 1999. Private firms made a major contribution to the increase in the number of IV, as did the number of IV from public sector research also accelerated rapidly. Identifying the role of policy change in increasing the number of maize IVs and maize yields is the main objective of this paper.

Such an analysis is important for a number of reasons. First, the main rationale for liberalizing agricultural input markets has been to encourage competition, innovation, and higher productivity. An analysis of productivity trends before and after liberalization will help establish whether this occurred, at least for the case of Kenya. Second, in the context of the Kenyan seed markets, some have suggested that liberalization policies have only been partially implemented as evident by the continued dominance of the public sector firm Kenya Seed Company (Swanckaert, 2012) and the presence of older varieties (Smale & Olwande, 2014). If it can be shown that there is an association between the number of maize varieties released and increased productivity, it would lend support to further reforms that enable greater varietal releases in not only Kenya but other countries. For example, Gisselquist et al. (2013) contend regulatory hurdles discourage firms from releasing new varieties in Africa with the implication that it limits productivity. Finally, while there are a number of studies that assess the impacts of modern inputs, nearly all have been at the level of the farm seeking to understand either farm impacts or some aspect of determinants of farm adoption. To our knowledge there has been no assessment of policies designed to increase input use have had on macro level productivity in SSA.

As such in this paper, the macro level determinants of maize productivity Kenya are examined, with a focus on policies to encourage private sector participation and the role of improved varieties. Our analysis consists of first examining production and yield trends to see whether yields changed, post liberalization. We employ a yield model to relate national maize yields with a number of exogenous factors. As one of the explanatory variables--the number of varieties--is likely endogenous with yield, we use public R&D, the number of Plant Breeder's Rights issued, and the years since private varieties have been introduced as instrument variables for the number of varieties in a two stage least square (2SLS) regression.

This paper proceeds by providing a background to maize production in Kenya, in particular a description of the maize seed system and policies and institutions affecting maize development. Section 3 presents the empirical model relating policy change ion innovation and maize productivity to innovation. The results are discussed in section 4. Section 5 concludes the paper.

2 Background

2.1 Maize in Kenya

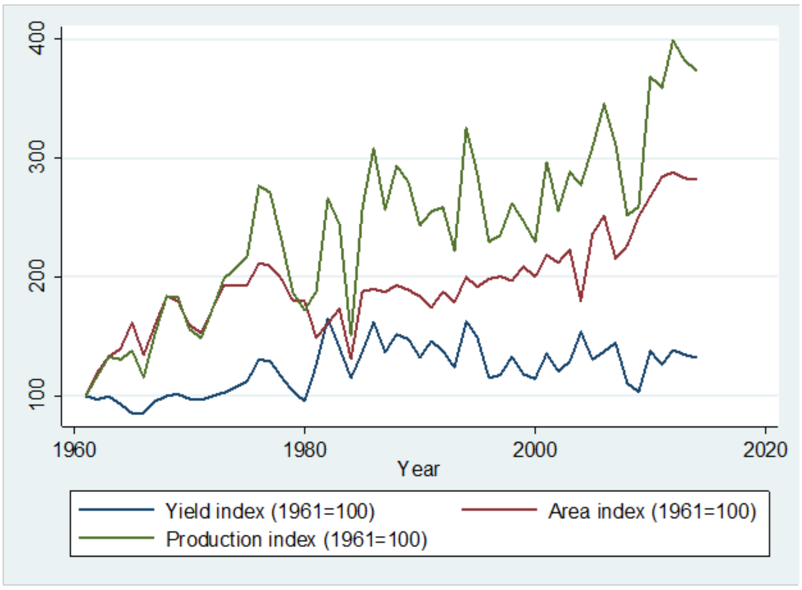
Maize is the main staple in Kenya, accounting for nearly 40% of cultivated area, 2.4% of Kenya's GDP and 12.65% of agricultural GDP (FAO, 2016). More than 75% of the maize production is due to small farmers, although only 20% of what is produced by smallholders is sold in the market (Chemonics, 2010). Kenya's per capita maize consumption is estimated to average 103 kg/person/yr (average for 2012-2014), compared to 73 kg/person/yr for Tanzania, 52 kg/person/yr for Ethiopia and 31 kg/person/yr for Uganda (FAO, 2016).

In spite of maize's importance for food security and the Kenya's economy, maize productivity and production growth rates are well below global averages. Figure 1 plots the trends in production, area and yields, while Figure 2 presents the same trends as indices (with 1961=100). As is evident from these trends, while production has increased 3.5x (from 1 MT in the early 1960s to 3.5 MT by mid 2010s) much of it was due to increase in area (which increased by 180%) rather than yields (that increased by 32%) (FAO, 2016).

Figure 1: Trends in maize yields, production and area for Kenya (1961-2015)

Source: FAO (2016)

Figure 2: Trends in maize yield, production and area indices for Kenya (1961=100; 1961-2015



Source: FAO (2016)

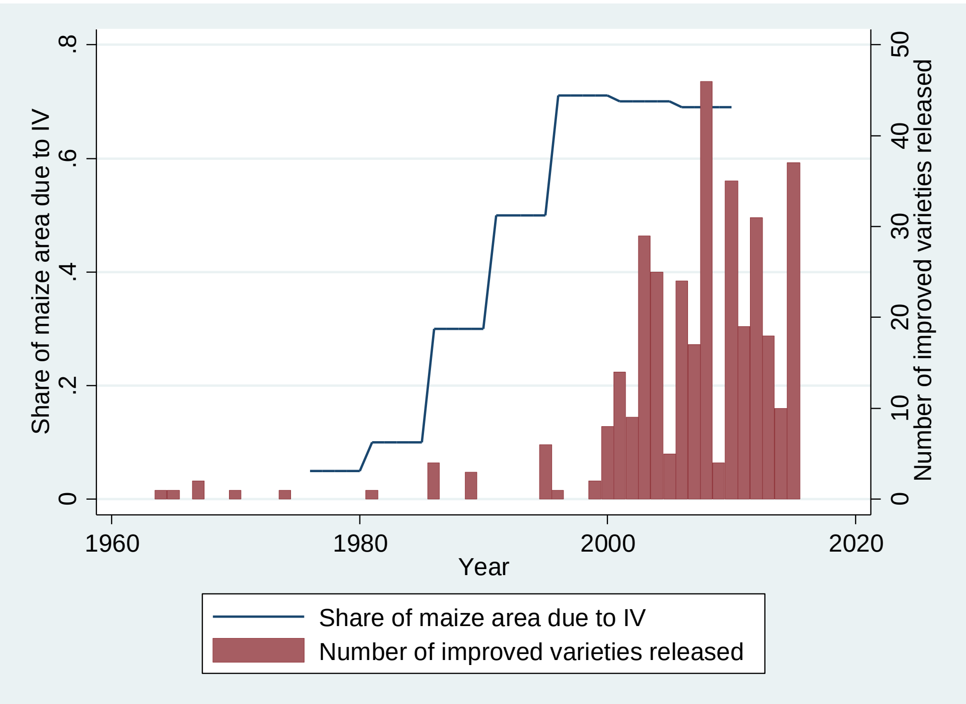
Compared to other regions, Kenya's maize yield is below that for SSA as a whole, and even below the regional average for East Africa (Table 1). Maize yields in Kenya are even lower than what U.S. farmers were able to obtain prior to the widespread adoption of hybrid maize. Adoption rates of IVs appear to have level off at 70% since the mid-90s, in spite of the large number of new varieties that have been released since 1999 (see Figure 3).

Table 1: Maize yields by key regions (2010-2014)

Region / Country	Average Yields (kg/ha) 2010-2014
Asia	4896
Sub-Saharan Africa	2188
East Africa	1772
Kenya	*1680*
West Africa	1631
Southern Africa	4238
Latin America	3912
North America	9444
Europe	6249
World	5268

Source: FAO (2016)

Figure 3: Adoption of IV of maize and release of new maize varieties (1961-2014)



Source: Authors based on data from DIIVA (2015) and KEPHIS (2016)

The low yield growth in spite of increasing adoption of IV is peculiar, but could be due to variety of reasons. First it may be that many of farmers are using older varieties, even if they are improved or modern. Varietal turnover--not just simply replacing the seed--has been found to be important for increasing productivity (Smale & Olwande, 2014; Spielman & Smale, 2017). New varieties not only allow farmers to maintain the yield gains of the previous generation, but also help him to withstand new forms of pests, diseases, drought and flood The optimal rate of varietal turnover depends not only on the crop in question and environmental factors, but importantly on economic factors. n area weighted age[1] (WA) of less than 10 years and adoption rates of 35% are generally considered indicators of good progress in plant breeding (Walker & Alwang, 2015)

Studies on varietal turnover for maize in Kenya suggest that WA has been declining but still is above 10 years. Smale and Olwande (2014) using a panel survey from 2004-2010 estimate the WA to be 17.3 years in 2010, while a more recent survey by Abate et al. (2017) estimate the WA age to be 13 years for 2013. Our own estimates based on a 2009 survey data from DIIVA[2] suggest the WA is 19 years, with nearly 43% of the area cultivated by varieties that are 10 years old or less (Table 2)

Table 2: Maize varietal adoption in Kenya (1993 and 2009)

	1993		2009	
	Variety	% Area	Variety	% Area
By Variety				
	H614D	41.8	H614D	22.6
	H625	22.9	SC DUMA 411	7.2
	H626	12.8	H624	4.7
	H511	7.2	Katumani	3.8
	Katumani	5.3	H6210	3.1
	Rest (5 var)	7.6	Rest (60 var)	35.5
	Total	97.6	Total	76.9
By Breeder				
Public (KARI/KSC)	100		74.8	
Private	0		25.2	
Seedco			*9.8*	
Pannar Seed			*7.3*	
Pioneer			*3.9*	
Western Seed Co.			*3.8*	
Monsanto			*3.7*	
By age				
<10 years	55.4		42.7	
10-20 years			14.2	
>20 years	42.8		43.1	
Weighted Age	23		19	

[1] Weighted average (WA) age is defined as $\sum_i p_{it} A_{it}$ where p_{it} is the proportion of the crop's area cultivated in variety i in year t,

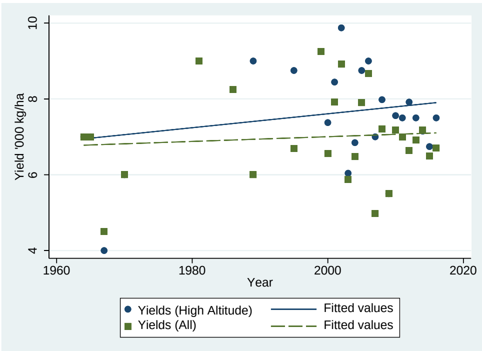
[2] DIIVA--or the Diffusion and Impact of Improved Varieties in Africa--is a CGIAR led project that seeks to collect improved varietal adoption data in Africa. Details about the project and associated dataset is available from https://www.asti.cgiar.org/diiva

Source: Hassan and Karanja (1997) for 1993 and CGIAR (2015) for 2009

Second, even if the new varieties that are released are adopted, they may not be improving much on the yields of the varieties they replace. Analyzing yield trends from 1960 to the early 90s Karanja (1996) found that "newly released varieties in 1989 had smaller yield advantages over their predecessors than the previously released ones... research yields were exhibiting a 'plateau effect'". For example the 1961 variety KSII with an experimental yield of 3500 kg/ha, was followed by H611 in 1964 (with a 40% yield advantage), then H622 (16%) and then H611C in 1971 (12%). H626 which was released in 1989 had a 1% yield advantage over H625 was released eight years earlier.

Figure 5 presents more recent data on average research yields of released varieties as documented by KEPHIS. Average yields of high altitude late maturing varieties have increased more than all varieties combined, although yields across all varieties have been stagnating and even declined in the more recent years.

Figure 4: Average experimental yields of released varieties (1960-2015)



Source: Generated using KEPHIS (2009)
Note: Each scatter point represents the average experimental yield of varieties released that year. We differentiate between all released varieties and varieties intended for the high altitude (high potential) areas.

Finally the mere release of new IVs--whether private or public--will not raise yields on its own. To have an impact on overall yields, the new varieties have to be superior to what is currently grown, widely adopted and complemented with other inputs, especially fertilizer. Based on a survey of smallholder maize farmers in Kenya, Nyangena and Juma (2014) find that inorganic fertilizers and improved varieties results in an increase in maize yields if adopted as a package, rather than separately. Similarly, Muraoka et al. (2016) find significant positive impacts on land productivity in the highlands of Kenya from agricultural intensification--i.e. the use of high-yielding varieties, fertilizer and intercropping.

2.2 Seed Development and Policies

Maize has been grown in Kenya since at least the 16th century when it was introduced by Arab traders to the coastal areas and expanded further with the arrival of European settlers. By the mid-20th century, nearly 44% of agricultural land was under maize cultivation--a proportion that has not changed much since. Formal development of the seed industry began in the mid 1950's when the colonial government initiated a maize research program in western Kenya. Since then the industry has gone through distinct development phases that can be delineated by productivity growth[3].

Table 3: Growth rates (%/yr) of Maize yield, area and production (1962-2014)

	1962-1982	1983-1999	2000-2014	1962-2014
Yield	2.99%	-0.86%	1.72%	1.40%
Area	2.89%	2.28%	2.62%	2.62%
Production	5.97%	2.27%	3.91%	4.20%
Varieties Released	7	16	294	317

Source: Yield, area and production growth rates calculated from FAO (2016). Varietal release data from KEPHIS.

The initial phase, a period spanning from the early 60's to the early 80's saw relatively high productivity growth, averaging around 3% per year c). The period was characterized by a strong national maize program, involving provision of inputs, extension and supportive policies (Karanja, 1996; Karanja, 2007). Pre-independence maize development was geared to the needs of large scale farmer with the first hybrid (H611) being released in 1965 and widely adopted, especially in the high potential Highlands (Gerhart, 1975). After independence in 1963, additional varieties suitable for other agro-ecological conditions were released. The Government's maize seed program was complemented by an extension program that introduced farmers to best agronomic practices (Karanja, 2007). This led many smallholders to adopt improved varieties. Their yields were lower than large farmers due in part to the limited use of fertilizer

[3] Hassan and Karanja (1997) also characterize Kenya's maize industry going through different phases, but for different time periods since their analysis was up to 1991.

(Karanja, 1996; Hassan & Karanja, 1997). This may explain why even though adoption of IV of maize was increasing in the initial periods, yields were fairly stagnant averaging around 1200 kg/ha for much of the late 60's and early 70s. Productivity improved for the period 1975-82, as improved seed was further adopted by farmers in low potential areas. By the end of 1982, 7 improved varieties were released as documented by varietal registration records of KEPHIS[4].

The second phase--from 1983 to 1999--experienced a decline in productivity even though there were more varieties released (Table 3). The new varieties, however, had a small yield advantage over the ones that they were intended to replace (Karanja, 1996). Others factors that have been cited for the decline in productivity growth, include a decrease in maize research funding, reduced competitiveness of maize, droughts and political instability (Hassan & Karanja, 1997; Karanja, 2007). During the 80's Kenya faced a deteriorating macroeconomic conditions and balance of payment problems that forced it to cut back on agricultural research including research on maize. Real maize R&D expenditure fell from a peak of 232 thousand Kenyan shillings in the 70's to 133 thousand by the mid-80s (Karanja, 2007). This was also the period of Structural Adjustment programmes and the general liberalization of the economy, whereby agricultural markets were deregulated and privatized, reduction in trade barriers, removal of price distortions, exchange rate adjustments, and decentralization. While the liberalization was meant to encourage competition in markets and more efficient of resources, it led to a weakening of some government institutions as they had to cope with limited resources (Gitau et al., 2009). Moreover the private sector did not have the capacity to undertake the role that was formerly being performed by the government sector resulting in poor performance of the agricultural sector and the economy as a whole (MAFAP, 2013)

The most recent phase--from 2000 onwards-- can be regarded as a period of renewal with productivity growth reversing the trends of the prior decade. This post liberalization period involved measures that sought to rationalize and consolidate the policies instituted during earlier periods (MAFAP, 2013). Munyi and Jonge (2015) count 131 pieces of legislation that have been overhauled since 2000, many of them through a consultative process of the different stakeholders involved. as noted by Gitau et al. (2009). Some of these changes were part of the government's Strategy for Revitalizing Agriculture that was initiated in 2005. There were two notable shifts that occurred under SRA (MAFAP, 2013; Poulton & Kanyinga, 2014). First, Kenya was to move away from the goal of achieving food self-sufficiency (the objective that guided much of the agricultural policy in earlier periods) to one that emphasized wealth creation and employment generation as

[4] There is some discrepancy in the literature as to how many varieties were released. Data from KEPHIS suggests 7 varieties released between 1962-1982, while Karanja (2007) reports 17 release and Hassan and Karanja (1997) 13.

a way to ensure food security. Secondly the complementary roles for private and public sector to ensure efficient functioning of markets and optimal resource allocation. Under SRA, the public sector was to provide a limited number of goods and services, and a reduced but more focused approach to regulating the market that cannot be achieved through private self-regulation (Alila & Atieno, 2006; MAFAP, 2013).

Policies that directly affect the supply and demand of improved maize varieties have also evolved over the years. Many of these policies relate to varietal trade, registration, and eventual release to farmer since most varieties are developed abroad. Prior to liberalization, while foreign germplasm and knowledge transfer was encouraged, the import of maize varieties was severely restricted. Like many import substitution policies, the goal was to promote the development of a local seed industry, but in reality only one firm benefited, namely the Kenya Seed Company (KSC). KSC--a government owned parastatal created in 1956-- had exclusive rights to market maize varieties developed by the Kenyan Agricultural Research Institute (KARI). Even to this day almost two decades after liberalization, KSC maintains exclusive rights to popular varieties developed by public breeding programs. Nevertheless, by 2015 there were 19 companies that had release 157 varieties and accounted for 32% of the market share (The African Seed Access Index, 2016).

With imports of maize varieties no longer restricted, the focus of policy reform has been on the ease and speed by which new varieties are made available to farmers. In Kenya, the introduction of new seed varieties is regulated by under the 1972 Seed and Plant Varieties Act (SPVA) and its subsequent amendments which require that firms submit them for official tests for value in cultivation and use (VCU). Varietal testing and registration is meant to ensure the genetic identity of a variety while protecting consumers, farmers and the environment from inferior varieties. Prior to liberalization, the approval and certification process was under the domain of KARI's National Seed Quality and Control Board. Reforms during the late 90s relegated these responsibility to KEPHIS--a newly created independent regulatory body.

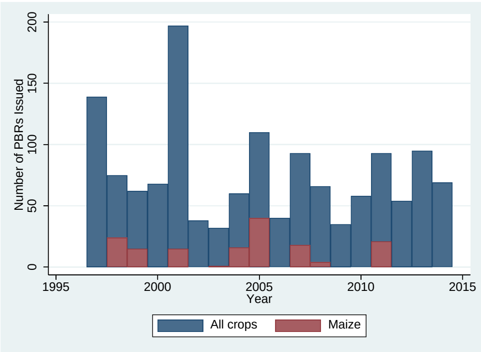
Despite this administrative change, the process of registration new varieties in Kenya is long and costly (Gisselquist et al., 2013; Smale, Byerlee, & Jayne, 2013). According to one survey, it took on average 32 month for a variety to go through the release process in 2016, which firms regard as being unsatisfactory. The approval process is considerably longer when compared to neighboring countries such as Uganda where it takes only 19.5 months to release a new variety (The African Seed Access Index, 2016). The total cost of registering and releasing a new variety is estimated to be nearly $3,240 or about 123% of Kenya's per capita income (World Bank, 2017).

A key provision of the 1972 SPVA were Plant Breeder's Rights (PBRs) as a way to protect the intellectual property of breeders and growers. However it was not until 1995 that regulations relating to PBRs provisions in the 1972 SPVA were put in place, leading to the first grant of such rights being made in 1997 (Munyi & Jonge, 2015). Initially Kenya acceded to UPOV under the 1978 convention, and to the 1991 UPOV convention when the SPVA was amended in 2012. Kenya's PBR legislation allow for the use of protected material for research, but prohibits the unauthorized marketing of "essentially derived varieties"--that is, varieties that are distinct from, but based almost entirely upon protected varieties (Swanckaert, 2012). Furthermore, it recognizes "farmers 'privilege" allowing farmers to save seed of a protected variety although not exchange it with other farmers (Munyi & Jonge, 2015).

Besides South Africa, Kenya is the only other country in Africa to have a system in place to grant PBRs. PBRs are issued by KEPHIS and available to all new plant varieties as long as it meets the criteria of being distinct, uniform and stable (DUS). Since PBRs came into force in 1997 and up to 2014, a total of 1384 PBRs were issued of which 154 were for maize (or 11%) (Figure 4). PBRs to maize account for majority of the PBRs issued to food crops, although it is distant second to rose which had 720 PBRs during this period.

Advocates for PBRs argue that it will stimulate research investments, allow greater flows of foreign sourced technology, a more competitive market that will eventually lead to greater number of yield increasing varieties. The evidence on the productivity impacts of PBRs in the U.S. and Canada suggests that there may be a small positive impact, but may depend on the crop being studied (Spielman & Ma, 2014). For example, Perrin, Hunnings, and Ilhnen (1983), Naseem, Oehmke, and Schimmelpfennig (2005) and Carew and Devadoss (2003) find limited positive yield impacts of PBRs on soybean, cotton and canola, respectively. However the evidence is more mixed for the case of wheat where Alston and Venner (2002) find no evidence of PBR on yields, while Kolady and Lesser (2009) do.

Figure 5: Number of Plant Breeders Rights Issued in Kenya (1997-2014)



Source: Generated using UPOV (2016)

Along with policy and regulatory changes that would affect the introduction of new maize varieties described above, policies related to the marketing and trade for maize were also being reformed. Before liberalization, maize prices were heavily controlled and set by the government affecting everyone along the maize value chain. Maize was marketed by the government's National Cereals and Produce Board (NCPB) which had a monopoly over all aspects of internal and external trade. Private trade across districts was illegal except with a permit. Such a regulated environment severely distorted the maize market and reduced the incentives for farmers to innovate and adopt productivity enhancing technologies.

Maize market reforms were initiated in the late 80's but intensified during much of the 90's (see (Nyangito & Karugia, 2002; Ariga & Jayne, 2009; Aylward et al., 2015) for a review of policies changes during this period). Early on, the reforms under the Cereal Sector Reforms Program were designed to allow interdistrict private trade, and a reduced role for NCPB in the procurement of maize. However prices were still controlled by NCPB and rather than increasing the margin between purchase and selling price to encourage private participation, margins declined (Sheahan, Ariga, & Jayne, 2016).

More intensive reforms were implemented in the mid 90s allowing for free movement of maize, removal of price controls along with direct subsidies to millers.

The private sector was allowed to import maize but faced a changing tariff structure. Initially import tariff was removed in 1993 but reimposed in 1995 and again in 1997. Jayne, Myers, and Nyoro (2008) find that maize import tariff over the 1995–2004 period raised average domestic prices by roughly 4 percent, although in several particular years, the import tariff raised domestic price levels by well over 10 percent. More recent trade measures have included the removal of tariff barriers with neighboring countries. Nevertheless the government continues to impose tariffs and export bans often in an unpredictable fashion.

Alongside reforms specific to the maize market, the fertilizer market has also been subject to considerable policy changes. Before market reforms, the market was controlled by government run agencies with limited private trade and controlled (subsidized) prices. Due to mismanagement, weak distribution networks and poor coordination, fertilizer did not reach many farmers. Reforms were introduced in the early 90s sought to address this as restriction on private traders, tariffs, and price controls were either all abolished or considerably relaxed. As a result by 1996, there were 12 major importers, 500 wholesalers and nearly 5,000 retailers (Ariga & Jayne, 2011). Fertilizer consumption grew at nearly 10% per year between 1990 and 2005, nearly double the rate 15 years prior (FAO, 2016).

More recent policies and programs directed at maize and fertilizer markets have sought to target resource-poor smallholder often by providing input subsidies. In particular after the 2008 world food price crisis and 2009 post-election violence, the government intervened to aid farmers. Nearly 30,000 tonnes of fertilizer was imported and distributed via NCPB branches and private retailers at a 40% subsidy. However the subsidies through NCPB have been found to lack clear targeting criteria and diverted to non-targeted beneficiaries by as much as 33% (Jayne et al., 2013).

3 Empirical Analysis

3.1 Empirical Model

The productivity of any crop is a function of a number of exogenous factors, from the types and amount of inputs used, agro-climatic conditions, technology employed, and the incentives/disincentives created by the policy environment. We hypothesize that the policy reforms that led to the opening of markets, technology development (in the form of new varietal releases), and Plant Breeder's Rights all had an impact on maize yields. Testing this hypothesis, however, is challenging for a number of reasons. First, the process of reforms take time and its effects may not be evident years later. As we discussed earlier, liberalization of agricultural sector in Kenya began in the late 80's but was enacted slowly and with considerable hesitancy especially with regards to maize marketing and trade. Second, policy reforms is a broad concept that involves changes to a number of different specific policies that may or may not have an impact on productivity. It is unclear, for example, whether reforms directed at removing price distortions (price policy) have the same impact on productivity as those that seek to improve access to technology to farmers (technology policy). If technology policy is more important to increasing productivity than price policy, and the latter is implemented first in the reform process, than the impacts of policy reforms may not be evident until after the technology policy comes into force. As such there needs to be clarity in terms of what is meant by policy reforms and when a specific policy change occurs. A third challenge is that data required to perform such a hypothesis test may not be available. For example, in a model that relates national maize yields to input use over time would require actual inputs (fertilizer, pesticides, labor) used by maize farmers, details on their use of improved varieties (how old; whether private or public; whether hybrid or not), and the agro-climactic conditions faced. Although we have some indication from farm level surveys of input use that have been carried out by different researchers, consistent aggregate level data specific for maize production is not available.

With these considerations in mind, we first specify the following general yield model

$$Y_t = \beta_{0t} + \beta_{1t}RAINFALL_t + \beta_{2t}FERTILIZER_t + \beta_{3t}IV\_MAIZE_t + \beta_{4t}P\_MAIZE_{t-1} + \beta_{5t}VAR\_MAIZE_t + u_t \quad (1)$$

where Y_t is the national maize yield for Kenya in kg/ha in year *t*. $RAINFALL_t$ is the total rainfall amount (mm) for Kenya in year *t*. Almost all agricultural production in Kenya is rainfed as less than 0.5% of the arable land is irrigated. While rainfall is an important factor in yield, the aggregate nature of this specific variable may misrepresent the actual rainfall received in maize growing regions located in the Western (Highlands) part of the country which are likely to be higher, as they benefit from bi-modal rainfall patterns (from short and long rain seasons). In the absence of such more detailed micro level rainfall data for the time period under study, average rainfall is used a proxy. $FERTILIZER_t$ is the amount of total fertilizer consumed (kg/ha of maize area) in year *t* and is constructed by dividing the total fertilizer nutrient (NPK) consumed in Kenya by the maize area. Like *RAINFALL*, this variable is an approximation of the actual fertilizer used by maize farmers as the consumption is for all crop production, not just maize. However since 50% of the fertilizer consumptions is due to maize (Oseko & Dienya, 2015) , and that maize is the most widely grown crop by area it is likely to be a good proxy. Indeed the fertilizer consumption variable constructed here correspond to those reported in farm level surveys (Ariga & Jayne, 2011). IV_MAIZE_t is share of maize area under improved varieties. The data for this variable comes from the DIIVA project which uses secondary sources and survey data to create a time series of area under modern varieties for different crops. Although the data is available for all the years of interest to us, the creators of the data series assumed that the share for all years between two survey points to be constant, resulting in the step-wise logistic curve as depicted in Figure 3. Given the lack of continuous and reliable time series on improved varietal adoption, we also use total maize area ($AREA_t$) as an alternative measure of maize cultivation P_MAIZE_{t-1} is the average producer price of maize in year *t-1*. Finally VAR_MAIZE_t is the total number of new maize varieties released in year *t*.

There are two issues with the last of these variables that need further elaboration. First, the number of maize varieties released says nothing about their adoption as many released varieties may never get adopted and even if they do, may be cultivated on a very small share of the total area. Data limitations prevent us to getting annual estimate how many of the released varieties are being adopted, but estimates from DIIVA from 2009 provide some indication. Of the 204 varieties that had been released and approved for cultivation up to that point 65 varieties were grown. Of these 5 varieties accounted for 65% of the cultivated area (see Table 1).

A second issue is that VAR_MAIZE_t is likely to be endogenous in equation (1) and the point estimates will be biased and inconsistent. We suspect endogeneity here because there may be unobservable factors that jointly determine yield (Y_t) as well as the number of varieties (VAR_MAIZE_t). For example, greater spending on research and technology development would not only lead to higher yielding varieties but also more varieties and varietal choice. In order to control for such endogeneity, we employ a two-stage least squares (2SLS) regression approach and introduce instrumental variables that are determinants of the number of varietal releases, but not affecting maize yields directly.

2SLS involves a first stage regression of VAR_MAIZE_t on all exogenous variables plus variables to be used as instruments. Some candidates for exclusion restriction are research and development expenditures related to maize development (or alternatively the number of researchers), varieties released by private firms, and the varieties that are protected by PBRs. All three variables are also related to policy change. Greater R&D--both public and private--would be suggestive of a policy shift that seeks to focus on increasing the productivity of agriculture and maize specifically. Unfortunately we do not have a continuous time series for private R&D as much of it fairly recent. Even so, the amount private R&D expenditure has been estimated to be extremely small relative to public R&D (1.6 to 3.2 million US$ in 2008 vs. 263 million for public as reported by Pray, Gisselquist, and Nagarajan (2011)). We also do not have research expenditures by commodity. Given these limitations, we settle on total agricultural expenditures by the public sector in year t as one of the instruments (denoted as $RESEARCH_t$ measured in constant 2011 US$ millions).

As noted earlier, in the pre-reform period there were no private firms developing or marketing maize seeds. This changed around 1996 as part of liberalization and with the first private variety released. The presence of private firms is captured by a dummy variable ($PRIVATE_t$) to indicate the release of varieties by private firms since 1996 (1 for ≥1996; 0 otherwise). Finally, PBRs are policy tool in their own right--would also indicate the availability of productive and valuable varieties. Kenya has been providing PBRs since 1996, issuing 154 PBRs for maize between 1996 and 2014. However, not all PBR protected varieties are released and not all released varieties have a PBR associated with them. Since only released varieties would impact productivity, we use the cumulative number of released varieties with PBRs in year t as the instrument (denoted as PBR_t).

Variable	Definition	Source of Data	Mean	Std. Dev.
Y_t	Maize yield (kg/ha)	FAO	1555.47	258.60
$FERTILIZER_t$	(Log) Fertilizer consumption (kg/ha)	FAO	3.04	0.56
$RAINFALL_t$	Rainfall amount (mm)	World Bank	54.87	8.85
P_MAIZE_{t-1}	(Log) Maize price (US$/tonne)	FAO	4.80	0.61
IV_MAIZE_t	Share of maize area under improved varieties (IV)	DIIVA	0.36	0.31
$AREA_t$	Maize area (‘000 ha)	FAO	1487.23	282.30
VAR_MAIZE_t	Number of maize varieties releases in year t	KEHPIS	6.22	10.87
$RESEARCH_t$	Public agricultural R&D expenditures (2011 US$ millions)	ASTI	190.78	60.89
PBR_t	Number of released maize varieties protected by PBRs	UPOV & KEPHIS	13.73	20.05
$PRIVATE_t$	Dummy variable to indicate private varieties (1 if >1996, 0 otherwise)	KEPHIS	0.33	0.48

Number of observation for all variables is 51, except maize price (50 observations) which was lagged by 1 year.

3.2 Results and Discussion

The empirical analysis on factors determining yield were explained with two sets of specifications, derived from equation (1) presented in the previous section, using both OLS and 2SLS are presented in Table 4. The only coefficient that is significant (at the 10% level) in the OLS regressions that directly accounts for yield is the lagged maize price. As one would expect higher prices induce yields likely due to intensification of external inputs use or through expansion of acreage. More specifically, here yields increase by 1.9 to 2.1 kg/ha from a 1% increase in producer maize prices. Intensification can occur through higher use of inputs such as fertilizer, high yielding seeds, pesticides, or labor. Since the coefficients on fertilizer and share of maize to improved varieties are not significant (and negative for IV_MAIZE_t) it would appear that intensification is occurring through higher labor use or some other input not accounted for here (such as manure). To know if acreage expansion have had any impact on maize productivity levels, we further accounted for maize area ($AREA_t$), which is proven to be negative and insignificant (Table 4). This is perhaps true (as described in Table 2), in Kenyan case; though maize acreage has been increasing over years, the expansion includes maize being grown in less productive regions with less productive cultivars resulting in increased yield variability across different agro-climatic zones (Abate et al., 2015).

The two sets of 2SLS estimates of the yield impact maintains the significance of lagged maize price variable[5], besides number of maize varietal releases and fertilizer consumption becoming significant at the 1% and 10% level, respectively. It is to note here that though there is a change in the signage of the share of improved varieties from the OLS estimates, the results still remains insignificant with high standard errors. Inclusion of area growth has slightly improved the overall model estimation, but maintaining the significance of the variables. As discussed above, all of the selected instruments viz., public R&D expenditures, presence of private firms, plant breeder's rights that affect VAR_MAIZE_t directly, is also expected to determining yield (Y_t). In our estimates, it was evident that, keeping all the exogenous factors i.e., *ceteris paribus*, while public R&D ($RESEARCH_t$), plant breeders rights (PBR_t) and presence of private firms ($PRIVATE_t$) all have a positive impact on number of varieties released, only the coefficient on the plant breeders rights variable is found to be significant (see Table A1 for the first stage estimation of 2 SLS results on varietal releases in Appendix). This suggests that PBRs are incentivizing breeders to release more varieties, as evidenced in

[5] Note the inclusion of maize area growth has further strengthened the validity of maize prices on yield increases.

the literature. The insignificance of the $RESEARCH_t$ coefficient is surprising, but one should note that it is measuring total public R&D and that dependent variable is total number of varietal release (both private and public). Since we are unable to differentiate all the variables in our dataset by firm type (i.e. public/private) public R&D may be an inefficient predictor of total releases.

To justify the appropriateness of the use of 2SLS over OLS, we perform a series of post-estimation tests for both specifications. First, endogeneity test for VAR_MAIZE_t with the null hypothesis that it can be treated as exogenous is rejected (Durbin (score) χ^2=11.3 (p=0.008; Wu-Hausmann F = 12.6 (p=0.0010)). Second to check whether the instruments are weakly identified, F statistic for the joint significance on the coefficients of the additional instruments F(2,41)=12.1 with p=0.000 hence rejecting the null hypothesis that the instruments are weakly identified. Finally, in the test for over identifying restriction, under the null hypothesis that the instrument set is valid and the model is correctly specified, the p values for both the Sargan (score) (χ^2=3.83 p=0.1470) and Basmann (χ^2=3.48 p=0.1755) are greater than 10% suggesting that the model is indeed valid. Similar post-estimation results are obtained when maize area ($AREA_t$) is used instead of IV_MAIZE_t.

Table 4: Results of the yield function; dependent variable Y_t

VARIABLES	(1) OLS	(2) 2SLS	(3) OLS	(4) 2SLS
VAR_MAIZE_t	-4.53	-17.11***	-3.13	-15.54**
	(3.863)	(6.018)	(4.0071)	(6.715)
$FERTILIZER_t$	157.19	248.83*	140.98	237.08*
	(113.966)	(133.658)	(102.858)	(122.877)
$RAINFALL_t$	3.67	4.644	3.85	4.53
	(3.670)	(3.954)	(3.616)	(3.849)
P_MAIZE_{t-1}	186.40*	194.51*	214.97**	200.51**
	(103.409)	(109.248)	(95.550)	(100.073)
IV_MAIZE_t	-105.47	12.55		
	(225.963)	(242.693)		
$AREA_t$			-0.27	-0.03
			(0.186)	(0.210)
Constant	53.30	-281.8	247.53	-234.43
	(499.295)	(576.301)	(340.096)	(438.878)
Observations	50	49	50	49
R-squared	0.306	0.069	0.326	0.1124

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

The key question to answer here is what is one to make of the negative but significant coefficient on the number of maize varieties released over years VAR_MAIZE_t and its relationship to yield levels of maize? Taken at face value it says that an additional varietal release decreases yields by 15- 17 kg/ha, thus one could see the disconnect between yield gains and new cultivar releases. Few other studies have also started with the assumption that more new varieties will lead to higher yields, but newer varieties offer small yield advantages over the previously released improved varieties (Ariga & Jayne, 2011; de Groot et al, 2006; Olwande and Smale, 2012). The liberalization policies with regard to input sector have resulted in increased private sector participation as well in varietal releases in the last decade, not many varieties were developed to address the agro-ecological concerns, including not addressing the issues related to varieties suitable for maize based intercropping situation, with poor genetic gains. As has been stated previously, perhaps not all released varieties get adopted and thus the negative coefficients is likely accounting for the non-adoption of new varieties. Note that that the share of maize area due to improved varieties, while positive, is insignificant. Since the share has not changed much over the last 20 years and already above 70%, the yield gains from increasing improved varietal share are not going to be large if the same (older) varieties are going to be adopted.

4 Conclusion

Since the early 1990's, Kenya has undertaken a number of reforms to liberalize its agricultural markets with a view of improving productivity. Agricultural input markets that were previously heavily regulated with little private sector participation have undergone dramatic changes, especially the maize seed market. Since the mid 1999, for example, 333 improved varieties have been released compared to 21 in all the years prior. Nearly half of the varieties released since 1999 have been due to private firms.

While policy reforms have been largely focused on improving the supply of new varieties and varietal development, it is unclear whether it has had the desired productivity impact. In this paper we addressed this question directly by relating Kenya's national maize yields with a number of exogenous factors, including those that are influenced by policy changes. The results of the 2SLS regression--where the first stage relates how different policies impact the development of new varieties and second stage on how those varieties influence yields--suggest that the release of new varieties does not have an effect on yields. The lack of increase in yield due to new varietal releases is surprising, considering newer releases are often regarded as being productive than the older ones they replace.

However the results are plausible when one considers that the adoption of the released varieties has not been widespread and that for many of the varieties released the yield advantage of the released varieties (over existing varieties) has been marginal. This suggests greater R&D investments to improve the productivity of new varieties and better traits for managing biotic and abiotic stresses. Policy needs to be directed towards encouraging the adoption of new varieties, specifically targeted to replace older or ‘tired’ varieties of maize. This requires concerted extension and dissemination efforts supported by Ministry of Agriculture, private sector and other local administrative officials.

Though Kenya has reformed its seed sector through liberalization, the government parastatal (Kenya Seed Company) still controls nearly 70% of the seed market, distributing seeds at subsidized prices. Under these circumstances, private firms are unable to compete effectively and discouraged from making investments that would allow them to introduce new varieties. Further policy reforms are therefore needed to enable further private firm entry and make the market more competitive.

5 References

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6 Appendix

Table A1: Reduced form (first stage) estimates; dependent variable VAR_MAIZE_t

VARIABLES	(1)	(2)
$FERTILIZER_t$	4.839	4.169
	(3.479)	(3.464)
$RAINFALL_t$	0.0701	0.073
	(0.114)	(0.115)
P_MAIZE_{t-1}	-3.111	-3.604
	(3.115)	(3.206)
IV_MAIZE_t	-10.79	
	(10.83)	
AREA		-0.0012
		(0.006)
$RESEARCH_t$	0.0142	-0.017
	(0.0413)	(0.0278)
PBR_t	0.379***	0.334**
	(0.131)	(0.130)
$PRIVATE_t$	6.935	7.216
	(4.438)	(4.481)
Constant	-3.857	4.602
	(16.42)	(15.422)
Observations	49	49
R-squared	0.702	0.695

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1