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PRIVATE INVESTMENT IN AGRICULTURAL RESEARCH AND TECHNOLOGY TRANSFER IN AFRICA

Carl Pray, David Gisselquist, and Latha Nagarajan

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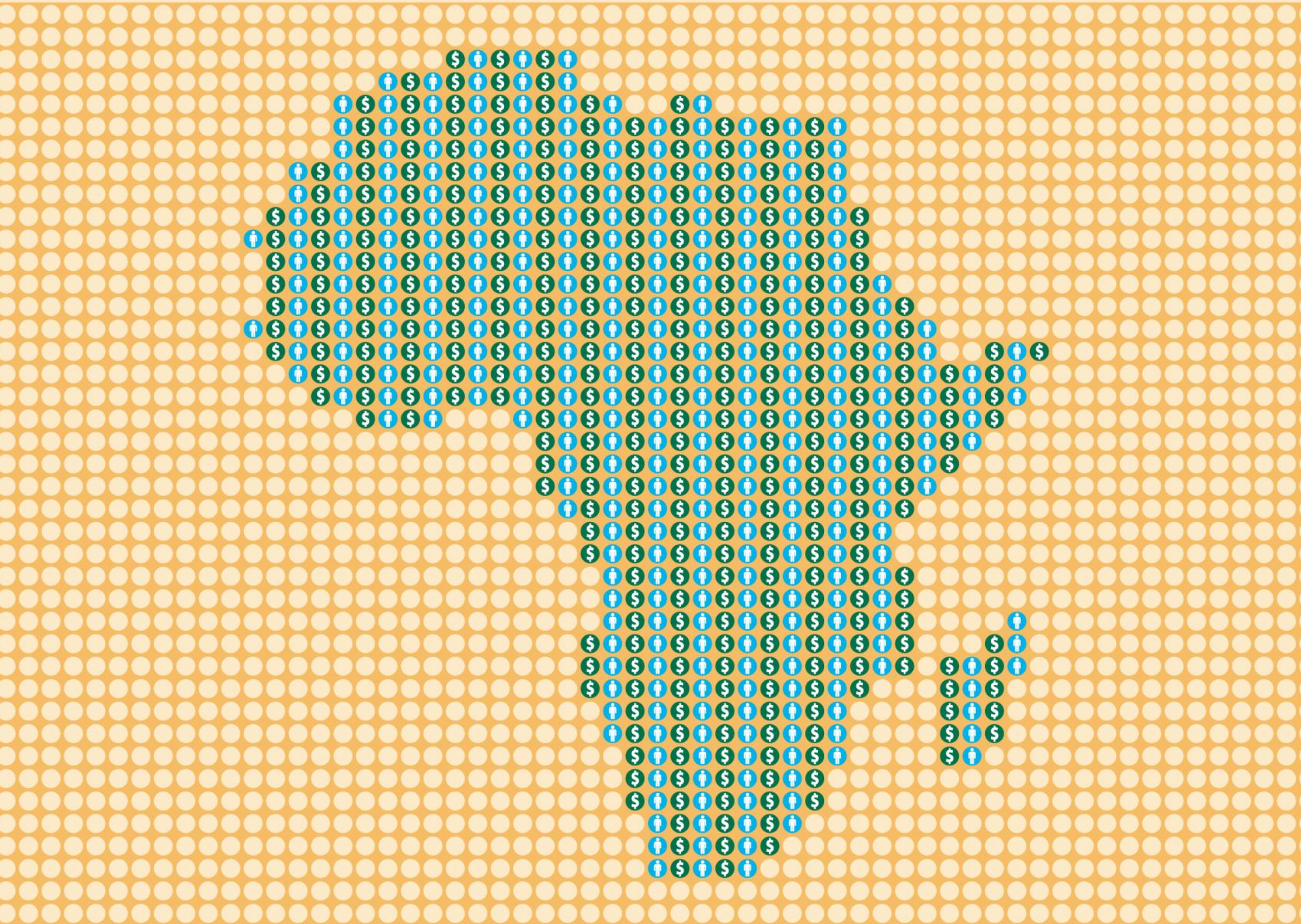
AGRICULTURAL R&D: INVESTING IN AFRICA'S FUTURE
Analyzing Trends, Challenges, and Opportunities



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About the Authors

Carl Pray (pray@aesop.rutgers.edu) is a professor at Rutgers University; **David Gisselquist** (david_gisselquist@yahoo.com) is a consultant; and **Latha Nagarajan** is a research associate at Rutgers University.

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Acronyms and Abbreviations

AgGDP	agricultural gross domestic product
AVRDC	Asian Vegetable Research Development Center
CAIS	Central Artificial Insemination Station
CGIAR	Consultative Group on International Agricultural Research
CIMMYT	International Maize and Wheat Improvement Center
CSS	Compagnie Sucriere Senegalaise [Senegalese Sugar Company]
DTMA	Drought Tolerant Maize for Africa
ECOWAS	Economic Community of West Africa
FTE	full-time equivalent
ICIPE	International Centre of Insect Physiology and Ecology
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IITA	International Institute of Tropical Agriculture
ILRI	International Livestock Research Institute
IPR	intellectual property rights
KARI	Kenya Agricultural Research Institute
KSC	Kenya Seed Company
KTRF	Kenya Tea Research Foundation
MRI	Maize Research Institute
NGO(s)	nongovernmental organization(s)
R&D	research and development
SAB	South Africa Breweries
SASRI	South African Sugarcane Research Institute
SSA	Sub-Saharan Africa
UEMOA	West African Economic and Monetary Union
WEMA	Water Efficient Maize for Africa

Abstract

This study is based on surveys of private-sector innovation and research in Kenya, Senegal, South Africa, Tanzania, and Zambia in 2009 and 2010. With the exception of South Africa, Private R&D in Sub-Saharan Africa is still limited, but it is growing rapidly in several countries and is concentrated in the seed industry. The study found that innovations in plant varieties, machinery, pesticides, fertilizers, and poultry imported by private agribusiness have been important sources of new agricultural technology. A search of the literature shows that private technology increased agricultural productivity in Africa. The adoption of proprietary hybrids of maize increased yields in Tanzania. Modern poultry technology increased poultry productivity in Nigeria, and private sugarcane research in South Africa increased productivity there. Many studies show that proprietary genetically modified maize and cotton improved the yields, incomes, and health of smallholder farmers in South Africa and Burkina Faso.

Government policies that encouraged research on private technology and its introduction include the liberalization of agricultural input and output markets by reducing trade barriers, eliminating government monopolies, and allowing local and foreign private firms to enter agribusiness. A second set of important policies include a stable policy and regulatory environment and reduced taxation on the agricultural sector. Once liberalization and favorable policies are in place, government investments in R&D and higher education and technology policies, such as strengthening patents, can encourage more private innovation and R&D.

1. INTRODUCTION

Substantial empirical evidence shows that technology from private research—such as new plant varieties, fertilizers, pesticides, machinery, veterinary pharmaceuticals, and poultry and swine breeds—has contributed to agricultural development, economic growth, and poverty reduction in developing countries (Pray and Echeverría 1991; Pray et al. 1991; and Pray, Johnson, and Fuglie 2007). Innovations from in-country research and private technology transfer, often with little or no formal adaptive research, have had a major impact on agriculture in developing countries. Private research has expanded rapidly in the past decade, notably in Asia, at a time when public-sector research in many countries, particularly in Sub-Saharan Africa (SSA), has stagnated or declined (Pray and Fuglie 2001; Beintema and Stads 2007, 2008). A number of African governments, often with the encouragement of foreign aid donors and private foundations, have pushed policies and invested in programs to encourage private agribusiness to finance and conduct agricultural research. On the other hand, some government scientists and nongovernmental organizations (NGOs) argue that private agribusiness has introduced very little technology and done little in-country research and development (R&D) of use to smallholder farmers and poor people, and that much of the technology introduced by the private sector has negative social and environmental effects.

The purpose of this paper is to attempt to document the amount of private R&D and technology transfer being undertaken in SSA, to identify its impact, and to suggest government policies and investments that might encourage the private sector to play a larger and more constructive role in the future. The paper focuses on five African countries—Kenya, Senegal, South Africa, Tanzania, and Zambia—and also provides some comparative data assembled by the study team in Bangladesh, India, and Pakistan. This paper builds on country studies undertaken during 2009–11 by teams that included scientists or economists from each country, and collaborators from the International Food Policy Research Institute (IFPRI), McGill University, and Rutgers University. Each country study involved the collection of data on innovations, research expenditures, and personnel from a sample of private organizations from all segments of agribusiness using a questionnaire developed by the team.

For most country studies, survey data on innovations were supplemented with data on patents, plant breeders' rights, or registrations of new plant varieties and pesticides. The private sector was defined to include firms with at least 51-percent private ownership, NGOs, private cooperatives, and research organizations primarily financed and managed by the private sector. Thus, research foundations and trusts funded through commodity taxes and managed by the government were excluded. Literature measuring the impact of private R&D was also assembled.

2. PRIVATE-SECTOR RESEARCH AND INNOVATION IN SUB-SAHARAN AFRICA

The private sector in all African countries in this study introduced many technologies that constitute in-country, if not global, innovations.[1] The study survey (IFPRI–McGill–Rutgers 2010/11) elicited information on recent innovations and their sources (Table 1). Although the number of firms in the sample was small, the data identify the industries with more innovations and the major sources of innovation. The most common type of firms reporting innovations were seed firms that imported or bred new plant varieties, followed by firms in the pesticide or processing industries (Table 1 combines data for all types of processing firms). Thereafter, the most common types of firms were those providing livestock inputs and agricultural machinery, and plantations. The major source of innovations for the

[1] The questionnaire defined a new technology or innovation as ". . . something that is new to the country, that is, yours is the first company in the country to adopt the innovation, even though it might already be widely used in other countries. A new technology or innovation might be, for example, a crop variety, a pesticide active ingredient, processing machinery, or a new process with or without new hardware or machinery."

seed and pesticide industries was imported technology. In the plantation and livestock input industries, imported technology was slightly more important than local sources. Local sources of innovation appear to be more important in the areas of food processing, fertilizers, and machinery.

Table 1.Sources of innovations from surveyed firms in the five case study countries

Activities	Number of organizations reporting innovations	Source of innovation: Locally developed – Company's own R&D	Source of innovation: Locally developed – Other R&D	Source of innovation: Imported – Via a parent company	Source of innovation: Imported – From another source
Input supply					
Seed	31	12	4	12	10
Fertilizer	4	2	1		1
Pesticide	12	3		6	5
Agricultural machinery	7	3	3	3	1
Livestock and fisheries inputs	9	4		3	4
Large-scale production					
Crops	6	2	2	3	2
Livestock					
Fisheries					
Processing					
Crops	5	3			2
Livestock	3	2	1		
Fisheries	3	3		1	
Total	**80**	**34**	**11**	**28**	**25**

Source: IFPRI–McGilll–Rutgers 2010/11.
Note: The five case study countries are Kenya, Senegal, South Africa, Tanzania, and Zambia. The source of innovations is based on the number of organizations for each source; hence, organizations may have more than one source. "Other R&D" includes in-country R&D funded and managed by someone else, such as a government agricultural research agency or university.

The country case studies noted some relatively new industries with many technical innovations. In Kenya the export-oriented floriculture industry has introduced biopesticides, fertigation (the application of fertilizers through irrigation water), new flower types and breeds, the use of solar energy, new greenhouse materials and equipment, and hydroponics (Odame, Kangai, and Spielman 2012). In Tanzania and Zambia entrepreneurs have introduced the new inedible oilseed crop jatropha for biofuel, and the Senegalese Sugar Company (CSS) is now producing ethanol from sugarcane (Sène and Stads 2011).

The only quantitative indicator of product innovations available for all countries is the number of registered (that is, government approved) new crop cultivars (Table 2). Private companies have been most successful in introducing maize hybrids. Since 2000, private companies have introduced between 37 and 105 maize cultivars in Kenya, Tanzania, and Zambia; 2 in Senegal; and 482 in South Africa. More cultivars give farmers more options, serve more agroecological conditions, and promote competitive markets. During this period, the private sector in South Africa, Tanzania, and Zambia introduced more maize cultivars than the public sector, almost as many in Kenya, but less than the public sector in Senegal. In Africa for crops other than the public sector has been the main source of new varieties with the exceptions of South Africa and Zambia where the private sector has developed many varieties of other crops.

Table 2. Cultivars registered for crops from public and private organizations in the five case study countries, 2000–08

	Kenya		Senegal		South Africa		Tanzania		Zambia	
Crops	**Private**	**Public**	**Private**	**Public**	**Private**	**Public**	**Private**	**Public**	**Private**	**Public**
Cereals										
Maize	67	70	2	8	482	16	37	10	105	8
Rice		7		16	0	0		5		2
Wheat		7			61	20		5	13	4
Sorghum	1	7			67	4		2	1	3
Barley	1				12	1	2			
Finger millet		1			0	0				1
Pearl millet		3			0	0				3
Other food crops										
Sweetpotatoes		5			na	na		6		5
Cassava		9			0	0		5		4
Potatoes					66	15			3	
Sunflower		3	3		61	5	2	3	6	0
Soybeans		5			84	8			11	2
Cowpeas	1	3			0	2		1		1
Groundnuts				7	2	11			4	1
Common beans		12			95	16		8	6	4
Sugarcane		10	1		37	na				
Fibers, drinks, drugs										
Tea	1	4			na	na				
Coffee					na	na		9		
Tobacco					10	11	3		6	
Cotton			2		33	3				1
Total	**71**	**146**	**8**	**31**	**1,010**	**92**	**44**	**54**	**155**	**39**
Number of private organizations with registered cultivars	10		5		95		10		10	

Sources: For Kenya, KPHIS 2008 and pers. com. Louis Sène; for South Africa, the 2010 variety list as maintained by the Registrar of Plant Improvement, which includes all varieties available in 2009; for Tanzania, the Tanzania Official Seed Certification Institute (TOSCI) 2008; for Zambia, Seed Control and Certification Institute (SCCI) 2008, and Setimala, Dadu-Apraku, and Mwangi 2009.

Notes: Data for groundnuts for Senegal are for 2000–09; totals are only for crops included in the table; the governments of Kenya, Senegal, Tanzania, and Zambia control and list cultivars for some or all other crops; na indicates that data were not available.

The data collected on private-sector R&D expenditures in 2008 have some limits. Some companies known to have R&D either did not respond to the survey or responded without providing data on R&D expenditures; as a result, survey findings underestimate private R&D. Country teams have estimated actual private R&D expenditure in 2008 based on their knowledge of the firms that did not provide R&D data (see the last two rows of Table 3). After reviewing the reports and cross-checking against earlier studies, it is estimated that these numbers reflect the actual levels of private R&D in these countries in 2008.

Table 3. Private institutions with R&D, research staff, and research budgets in selected countries, 2008

	South Africa		Kenya		Senegal		Tanzania		Zambia	
Industry	Researchers	R&D spending (thousand dollars)	Researchers	R&D spending (thousand dollars)	Researchers	R&D spending (thousand dollars)	Researchers	R&D spending (thousand dollars)	Researchers	R&D spending (thousand dollars)
Input supply										
Seed	95	19,000	8	640	19	NR	16	222	7	670
Fertilizer			2	NR	3	NR	7			
Pesticide	6	3,000			5	NR			2	
Machinery							1	NR	1	NR
Livestock and fisheries inputs	9	2,000	0	NR	7	NR			5	
Plantation					**9**	**NR**	**4**	**NR**		
Processing										
Crop	91	16,000	2	NR	5	NR	4	143	10	490
Livestock										
Fish					13					
Total for surveyed organizations	201	41,000	12	1,600	61	3,600	32	900	25	1,300
Estimated actual total		**50,000**		**3,200**		**4,700**		**1,800**		**2,500**

Source: IFPRI–McGill–Rutgers 2010/11.

Notes: NR indicates that data are not reported to protect the organizations' confidentiality, given that only one company in each of these categories reported research. Data on researchers are for individuals, not full-time equivalents; some organizations reported that research staff may also have part-time nonresearch duties. The estimated actual data for South Africa (that is, the last row of the table) include estimates of private research spending by companies that were not contacted or that did not return questionnaires. For example, in the case of South Africa, major research programs, such as Pioneer, Illovo Sugar, SAPPI, and Mondi did not respond to the questionnaire so as much as an estimated 20 percent of the country's private research could have been omitted. Similarly, in Kenya as much as half the country's private research could have been omitted given lack of data for Del Monte and floriculture firms such as Oserian. As much as half the country's private research, primarily on commercial crops like tobacco and sugarcane, could have been omitted.

Among SSA countries, South Africa has the most private agricultural R&D. Seed industry R&D is the largest component, followed by sugarcane and citrus research, which are performed by private organizations paid for by these industries. In the study sample, Senegal has the next-largest private R&D expenditures and number of scientists. Much of Senegal's private research is in several recently privatized corporations processing peanuts and cotton, and in a sugar mill that conducts research on sugarcane, sugar milling, and biofuels. In the sample, Kenya recorded the third-highest private R&D expenditures in 2008. A number of companies in Kenya invest in plant breeding, and a few invest in R&D for fertilizers and processing. Whereas private sugar mills and tea and coffee plantations in some other African countries manage research for these commercial crops, in Kenya such research is conducted by government institutes and is paid for by a combination of funds derived through levies and government contributions. Zambia has the next highest R&D expenditures, with research concentrated in seed and sugar. In the study sample, private firms in Tanzania spent the least on R&D, although Tanzania employs more private scientists than either Kenya or Zambia.

The two industries that have attracted the most R&D investment in Africa are the seed and processing industries (Table 3). This pattern is common across all five case study countries. Research on livestock inputs and pesticides (primarily trials for registration) is important in South Africa, Senegal, and Zambia. Research on sugarcane is important in Senegal and Zambia, as is research on tea and coffee in Tanzania.

Private R&D expenditures, researcher numbers, and research intensity (the ratio of agricultural R&D expenditure to agricultural gross domestic product [AgGDP]) for both the African and Asian countries in the study survey are shown in Table 4 (compilation of comparable data for Pakistan is ongoing). India, by far the largest country in the study, has far more research and scientists than the African countries or Bangladesh. At 0.6 percent, South Africa's research intensity is the highest among the study countries, followed by Senegal. Zambia has relatively high research intensity, but only because it has a small agricultural sector. Kenya and Tanzania, which have small R&D expenditures and large agricultural sectors, recorded the lowest R&D intensities of the study countries.

Table 4. Private-sector R&D in seven of the study countries, 2008

Measures	Kenya	Senegal	South Africa	Tanzania	Zambia	Bangladesh	India
Private R&D (million 2008 U.S. dollars)	1.6–3.2	3.6–4.7	41–50	0.9–1.8	1.3–2.5	10–20	251
Private R&D as a share of AgGDP	0.25–0.05	0.18–24	0.49–0.60	0.015–0.03	0.05–0.09	0.07–0.13	0.115
Number of scientists	12	61	201	32	25	119	2,190
AgGDP (billion 2008 U.S. dollars)	6.3	2	8.3	6.2	2.8	15	218

Sources: IFPRI–McGill–Rutgers 2010/11; AgGDP was calculated from World Bank 2011.

In South Africa, Senegal, and Zambia evidence of the overall growth of private R&D is clear. All the countries in the sample showed evidence of growth in plant breeding, and in Kenya livestock-related research appears to be growing, (data on other industries in Kenya and Tanzania are insufficient to allow a determination). A recent study suggests that private research on plantation crops and processing has declined in Kenya (Ndii and Byerlee 2004).

Most of the innovations from technology transfer and in-country research recorded through the survey were produced by African firms, some of which are regional multinational corporations. In addition, multinational corporations headquartered in Europe, the United States, India, and other countries play an important role in technology transfer in all five countries, and in R&D in several. In South Africa, the United States, and Europe, firms conduct about half the seed and biotech research; other research is conducted by South Africa–based firms, some of which are themselves multinational corporations—for example, Pannar (seeds), Illovo Sugar, and South Africa Breweries (SAB). In Kenya, both Africa-based multinational corporations, such as Pannar and Zimbabwe's SeedCo, as well as Pioneer and Monsanto, have small research programs. Monsanto's and Pioneer's main African research and seed production programs are in South Africa and serve both South Africa and its neighbors; each has smaller research stations in Kenya for the East African region. Pannar conducts its research primarily in South Africa and has small programs to test and introduce hybrids in Kenya. SeedCo conducts most of its research in Zambia and Zimbabwe, and has a small research program for high altitude hybrids in Kenya. Multinational corporations are also active in research on tobacco, fruit, sugarcane, and tea in East Africa and in sugarcane in Senegal.

3. THE IMPACT OF PRIVATE-SECTOR R&D AND INNOVATION

Studies that quantify the impact of private innovation and R&D in Africa are very limited. A number of studies show that maize hybrids and improved open pollinated maize varieties give higher yields than landraces (Hassan, Mekuria, and Mwangi 2001). Until the mid-1990s almost all maize hybrids came from public breeding, except in South Africa. Since 2000 the private sector has taken the lead in many more countries (Table 2). A recent study by the University of Göettingen and International Maize and Wheat Improvement Center (CIMMYT) is the first economic analysis of the impact of proprietary hybrids in Africa (Kathage et al. 2011). That study surveyed 695 farmers in the northern highlands and eastern lowlands of Tanzania. It found that switching to proprietary hybrids increased yields by 58 percent over open pollinated varieties despite virtually no use of fertilizer, pesticides, or irrigation; farmers using hybrid seed realized higher net incomes. This is consistent with several Indian studies (Pray et al. 1991;

Pray and Ramaswami 2001) that find proprietary hybrids of maize, pearl millet, and rice made substantial contributions to yields above those achieved with hybrids and open-pollinated varieties developed by the government and the centers of the Consultative Group on International Agricultural Research (CGIAR); these studies also found that most of the benefits from private research (that is, the development of hybrids) were captured by Indian farmers, not the seed companies.

The private sector has provided most of the inputs and knowledge required for confined poultry production, which is expanding rapidly in Africa (Alabi and Alabi 2009). Only one study has examined poultry productivity growth in SSA, focusing on the impact of trade liberalization on poultry productivity in Nigeria; between 1961 and 2005, poultry productivity growth was highest during the liberalization period 1986–94 (Alabi and Alabi 2009). Although this study does not model the specific role of private technology, it is consistent with findings of a global econometric model of poultry productivity during 1961–2005, which included Egypt, South Africa, and Zimbabwe (Narrod, Pray, and Tiongco 2008). That model found that imported private-sector technology, including breeding stock, medicine, and feed, were the most important factors in explaining broiler productivity growth.

There is one economic study of the impact of privately funded sugarcane research by the South African Sugarcane Research Institute (SASRI) and its predecessors (Nieuwoudt and Nieuwoudt 2004). Econometric estimates of the determinants of sucrose yield per hectare during 1925–2001 found that private research expenditures were positive and highly significant in explaining the growth of sugarcane yields. The study calculated a rate of return to research, development, and extension of 17 percent, which is high considering the opportunity cost of money, and that costs included expenditures on agricultural extension.

All other studies on the impact of private research examine the impact of proprietary plant biotechnology on smallholders in South Africa, plus some recent studies in Burkina Faso. Qaim (2009) analyzed these studies using a standard framework (Table 5). Studies in South Africa found that *Bt* cotton reduced pesticide use per hectare by 33 percent, increased yields by 22 percent, and increased the net margin by $91 per hectare, which was substantial for smallholder farmers in South Africa's KwaZulu Natal province.

Table 5. The impact of genetically modified crops in South Africa and Burkina Faso

Country	Crop	Pesticide reduction (%)	Yield increase (%)	Net margin increase (dollars per hectare)	Source
South Africa	*Bt* Cotton	33	22	91	Thirtle et al. 2003 Gouse, Schimmelpfennig, and Kirsten 2004
	Bt Maize	10	11	41	Brookes and Barfoot 2005 Gouse et al.2006
	Roundup Ready maize	–79	85	576	Gouse et al. 2009
Burkina Faso	*Bt* cotton	90	24	61	Vitale et al. 2010

Sources: Summary data on South African *Bt* cotton and *Bt* maize from Qaim 2009; others from original sources.

In KwaZulu Natal *Bt* maize provided considerably higher yields than conventional maize in years when there were stalk borer attacks; however, in years when stalk borers were not a serious problem, the farmers' only benefit was the assurance that the pests would not be a problem. Combining the results reported in Brookes and Barfoot (2005) and Gouse et al.(2006), use of *Bt* maize reduced pesticide use by about 10 percent, increased yields 11 percent, and increased net margins $41 per hectare.

Also in KwaZulu Natal, 2006/07 was the first year that enough farmers were using Roundup Ready hybrid maize to measure its impact. Yields were much higher than from conventional hybrids, possibly due to better weed control, but also due to better management by the farmers growing Roundup Ready maize (Gouse et al. 2009). Seed costs doubled, and herbicide costs rose from nothing to

US$84 per hectare, but the gross margin (value output –cost of intermediate inputs) with Roundup Ready hybrids was US$576 per hectare higher than with conventional maize.

Second-generation *Bt* cotton varieties with two stacked *Bt* genes were first used commercially in Burkina Faso in 2009 and were quickly adopted on about 125,000 hectares (Vitale et al. 2010). In plots with second-generation *Bt* cotton, pesticide use was reduced by 90 percent, yield increased by 24 percent, and the net margin was US$61 per hectare.

Two studies provide information on the health impacts of genetically modified maize. Bennett, Morse, and Ismael (2003) showed that the adoption of *Bt* cotton by smallholders in KwaZulu Natal reduced pesticide use and improved human health. Based on interviews with farmers and visits to clinics near the cotton-producing area, they found a decline in pesticide-related illness after the introduction of *Bt* cotton. A study among smallholder maize producers in KwaZulu Natal (Pray et al. 2011) provides evidence that the adoption of *Bt* maize reduces the exposure of farmers and rural consumers to mycotoxins that can cause esophageal cancer and birth defects.

4. HOW IMPORTANT ARE POLICIES IN EXPLAINING PRIVATE INNOVATION AND R&D IN AFRICA?

Since technology introduced by the private sector—through technology transfer from other countries, as well as from in-country private research—can boost smallholder farmers' production levels and incomes, reduce pesticide use, and in some cases improve health, what can governments do to encourage private agricultural innovation? This question is explored in below.

Factors Influencing the Current Pattern of Private Research

Firms will innovate to protect their market or if they see an opportunity for profit. Most innovations depend at least in part on technology transfer from other countries; depending on the technology source, intended market, and agricultural subsector, a lot of technology is borrowed in with little or no change, especially for smaller countries and markets. Depending on expected market size (whether in a single country or multiple countries), along with many other factors, companies will invest in in-country R&D. New products either from technology transfer or a firm's own R&D must have an expected market large enough and with prices high enough to pay for the costs of finding, developing, and introducing innovations.

The size of a country's agricultural sector influences sales and hence incentives to innovate. One measure of the size of the agricultural sector is AgGDP (Table 6, row 1). In terms of AgGDP, the biggest African country in the sample is South Africa, with US$8.3 billion in 2008, and the smallest is Senegal, withUS$2 billion in 2008. In contrast, that same year Bangladesh's AgGDP was US$15 billion and India's is US$281 billion, more than all African countries together. In India, technology from research anywhere in the country is able to reach a large national market, whereas in Africa, innovations must cross more than 40 national boundaries to reach an equally large market (Table 4).

Table 6.Indicators of polices that influence the profitability of private research, selected countries

	Kenya	Senegal	South Africa	Tanzania	Zambia	Bangladesh	India
Private R&D (million 2008 U.S. dollars)	1.6–3.2	3.6–4.7	41.0–50	0.9–1.8	1.3–2.5	10–20	251.0
Market size AgGDP (billion 2008 U.S. dollars)	6.3	2	8.3	6.2	2.8	15.1	218.1
Policies (nominal rates of assistance to agriculture, 2000–04)	9.3	–7.5	–0.1	–12.4	–28.5	3.9	15.8
Intellectual property rights Index, 2005	3.22	2.93	4.25	2.64	1.94	1.87	3.76
Ease of doing business, 2009	98	152	34	128	76	107	134
Government research (number of government scientists, 2002)	704	116	677	513	120	1,610	5,103
Number of university scientists, 2002	180	22	137	84	22	197	8,045
Public agricultural R&D (million 2002 U.S. dollars)	263	50	585	78	197	218	2,713
Public agricultural R&D intensity	1.22	1.21	2.16	0.28	0.44	0.36	0.37
Factors							
AgGDP (billion 2008 US dollars)	6.3	2	8.3	6.2	2.8	15.1	218.1
Nominal rates of assistance to agriculture, 2000–04	9.3	–7.5	–0.1	–12.4	–28.5	3.9	15.8
Intellectual property rights Index, 2005	3.22	2.93	4.25	2.64	1.94	1.87	3.76
Ease of doing business,2009	98	152	34	128	76	107	134
Government scientists, 2002	704	116	677	513	120	1,610	5,103
University scientists, 2002	180	22	137	84	22	197	8,045
Public R&D (million 2002 US dollars)	263	50	585	78	197	218	2,713
Public R&D intensity	1.22	1.21	2.16	0.28	0.44	0.36	0.37

Sources: Public-sector R&D data are from ASTI, various years; AgGDP data are from World Bank 2011; intellectual property rights index data are from Walter Park 2008; ease of doing business index data are from International Finance Corporation; and nominal rates of assistance to agriculture are from Anderson and Valenzuela 2008.

Although governments cannot do much in the short term about the size of a country's AgGDP, they can dramatically enlarge the markets in which their companies and farmers operate by reducing barriers to trade and technology flows from other countries. By allowing companies and farmers to access regional or world markets and technology, governments increase returns to private innovation, and thereby stimulate more innovation.

Economic policies (such as taxes and subsidies) that are neutral or favorable to agriculture encourage private agricultural activities, including innovation. The nominal rate of assistance to agriculture, developed by Kym Anderson at the World Bank (Anderson and Valenzuela 2008), is positive if agriculture is subsidized and negative if it is taxed. Senegal, Tanzania, and Zambia tax agriculture; South Africa is neutral; and Kenya subsidizes agriculture (Table 6, row 2).

Other factors also affect companies' decisions to transfer technology or invest in R&D, including the government's efficiency in providing basic services, the role of public corporations, controls on private firms, and the strength of intellectual property rights (IPR).The World Bank's International Finance Corporation publishes an annual index on the ease of doing business, which considers corruption, the ease of starting a business or of bankruptcy, and so on. South Africa, Zambia, and Kenya rank 34th, 76th, and 98th, respectively, among 183 countries. Governments can squeeze private companies by subsidizing or otherwise favoring public enterprises, such as the Kenya Seed Company (KSC) in Kenya. Government policies that limit foreign private investment (such as controls on the percentage of foreign ownership allowed) discourage not only private investment, but also innovation and R&D.

The ability of agricultural input firms to capture some of the benefits of new technology is influenced by the strength of a country's IPR. Park's (2008) index of the strength of IPR ranges from 0 to 5. With a score of 4.25, South Africa has the strongest IPR of the sample countries; scores for the other African countries in the study sample range from 1.94 to 3.22 (Table 6, row 3). In some cases, firms can protect their investments in innovation by offering technologies that are difficult to copy for technical reasons, such as hybrid cultivars or pesticides produced using complicated chemistry.

Aside from economic and industrial policies, agricultural innovation is also influenced, obstructed, or permitted by regulations specific to agriculture. Regulations are needed to protect the environment and health (Table 7, last row); however, many governments regulate the introduction of new cultivars and other input-embodied agricultural technologies on the basis of government tests of technology performance. Regulations vary by country and input (Table 7). For example, South Africa does not test new maize cultivars for performance; companies and farmers decide which hybrids perform well enough to plant. Governments of the other four countries in the African sample regulate the introduction of maize cultivars by performance, but only two—Senegal and Tanzania—regulate the introduction of vegetable cultivars by performance.

Table 7. Presence of performance-based controls on the introduction of new agricultural technology

Country	Field crop cultivars	Vegetable cultivars	Livestock semen	Livestock feed	Fertilizer	No-risk pesticide
Kenya	Yes for all field crops, with the exception of forage crops	No	Yes, but does not seem to be a significant barrier	na	Yes	Yes
Senegal	Yes for all crops	Yes	Yes	na	na	Yes
South Africa	No; varieties must be registered, but it's automatic	No varieties must be registered, but it's automatic	na	na	na	Yes
Tanzania	Yes for all crops	Yes	na	na	na	Yes
Zambia	Yes for all field crops (except forage crops)	No	Yes, but does not seem to be a significant barrier	Yes, but does not seem to be much of a barrier		Yes
Regulations needed to protect farmers, health, and the environment	Phytosanitary controls on seed imports; truth-in-labeling at the retail level	Phytosanitary controls on seed imports; truth-in-labeling at the retail level	Zoo-sanitary controls on live animal, semen, and egg imports	Prohibitions on dangerous components; truth-in-labeling	Prohibitions on dangerous components; truth-in-labeling	Controls on the introduction of dangerous chemicals and exotic biocontrol agents; truth-in-labeling

Source: IFPRI–McGill–Rutgers 2010/11, plus key informants and additional documents.

Notes: No-risk pesticide includes, for example, pheromones; dangerous components include, for example, heavy metals; na indicates that data were not available.

One of the main factors influencing a company's research costs is the availability of scientists and the amount of research conducted by the public sector (Table 6, last four rows). Government research institutes and universities are the main sources of scientists to private R&D institutes. Many scientists also work for CGIAR research institutes in Kenya; the International Livestock Research Institute (ILRI) and World Agroforestry Centre are headquartered there, and CIMMYT, the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), and the International Institute of Tropical Agriculture (IITA) have major regional research programs there. In addition, a number of international centers outside the CGIAR, such as the International Centre of Insect Physiology and Ecology (ICIPE), have headquarters in Kenya. Tanzania, which has an Asian Vegetable Research Development Center (AVRDC), is the only other country in the African sample hosting a branch of an international agricultural research center.

Given the information in Tables 6 and 7, it is no surprise that South Africa is the leader in private research in Africa. Its agricultural economy is large by African standards, and it has minimal restrictions on the importation of technology—for example, it allows the introduction of new cultivars from conventional breeding without performance tests. It does not restrict exports of agricultural products, and it does not heavily tax (or subsidize) Agriculture. IPR are stronger than in any of the other African or Asian countries under study, and the ease of doing business in South Africa is the highest of the eight countries. It has the second-largest number of government and university scientists in the African sample after Kenya, and it spends twice as much on public research as Kenya. An additional set of policies, which supports private R&D in South Africa but not elsewhere in Africa, comprises regulations that allow the adoption of biotechnology, which has been an important stimulus to research related to seed, forestry, and sugarcane in South Africa.

The amount of private R&D in other countries is less easily explained by Tables 6 and 7. Kenya's agricultural markets are sufficiently large to stimulate investment; with $6.3 billion in AgGDP, Kenya has the second-largest agricultural economy of the African countries in the sample, and although its IPR are weaker than South Africa's, they are stronger than other African countries. The business climate index is much lower than South Africa's but much better than Senegal's or Tanzania's. Finally, Kenya's economic policies provide a net subsidy to the agricultural sector, in contrast to all other African countries in the study sample. In addition, Kenya has the highest number of public-sector research scientists and the highest public expenditure on research. Despite this, Kenya has the least private agricultural R&D of the countries in the sample. One possible explanation is that liberalization and privatization have not gone as far or as fast in Kenya as they have elsewhere.

In contrast to Kenya, Senegal is surprising because it has more private research than expected. Its AgGDP is low, it taxes agriculture, the business climate is dismal, and IPR are weak. It also has the lowest number of public-sector scientists. At least part of the explanation for private companies' large investment in research in Senegal may lie in the structure of the input and processing industries, where private firms have considerable market power (see the next section).

Low levels of private R&D in Zambia are partly due to its small market and heavy indirect taxes on agriculture. It has a nominal rate of assistance of –28.5, the worst in the sample. In addition, Zambia's IPR index is lowest, whereas its business climate rating falls in the middle of the sample African countries. Zambia has an advantage when it comes to technology transfer, in that the country can easily import technology from South Africa (and maize-related technology from Zimbabwe). Tanzania has almost all the same factors that make Zambia's private R&D low, except that it is one of the larger agricultural economies in the region.

Of the policies and programs controlled by governments, all of those considered for this study support South Africa's leading position in private innovation and R&D, and go a long way to explaining what happens in Tanzania and Zambia. However, Senegal's favorable private R&D performance and Kenya's low effort are unexpected and may have to be explained by additional factors, including historic processes specific to those countries.

Policies Affecting the Expansion of Private Technology Transfer and R&D

As concluded earlier in this paper, private innovation and R&D have grown in Senegal, South Africa, and Zambia in the past decade. In Kenya, growth in private research on seed, chemicals, and livestock may have been offset by declines in other subsectors, such as processing and plantations. A Kenyan government survey from the mid-1980s estimated the value of R&D by commercial enterprises at US$1.25 million (Ndii and Byerlee 2004), which is not much different from the $1.6 to $3.2 million estimated by the current study, and actually more than the current figure if corrected for inflation. In Tanzania more private technology is coming in, but the trends in private innovation and research are not clear.

Liberalization of agricultural input industries, large-scale production, processing industries, and trade has had a major impact on the development of private agricultural research in all of these countries. Liberalization has included opening agricultural input and output markets, which had been monopolies controlled by parastatal organizations or commodity boards, to competition from national and international firms. Overvalued exchange rates that disfavored agriculture and agricultural exports have been reduced. In some countries governments have privatized agricultural input parastatals. Table 8 summarizes the evolution of the input and processing industries with special attention to private innovation and R&D.

Table 8. The evolution of industry structure and research in agricultural input and processing industries

Industry	Colonial period	Independence/ nationalization	Liberalization/ privatization	Present
Maize seed industry	Government research and commercial farmers' seed cooperatives	Government research continues; government seed companies (Zamseed, Tanseed, and Kenya SeedCo) have monopolies on maize seed; no private research	Government seed companies privatized (except in Kenya); some private cultivars registered; private companies enter the market; private R&D starts	Competitive industries in Zambia, Tanzania, and Kenya; private R&D grows
Other field and vegetable crops	Local supply, some private imports	Some private supply, including imports; some government R&D	More private vegetable cultivars introduced, but few for field crops; private R&D begins	More private vegetable cultivars, few field crops; private R&D expands but is still small
Pesticide, fertilizer, and machinery	Imports for commercial farmers	Government monopolies on imports and distribution of inputs, particularly fertilizers	Liberalization of imports and reduction in import duties and value-added tax	Growing presence of Chinese and Indian generic pesticides and machinery
Plantations and export processing industries	Private statutory monopolies or commodity boards; private research organized by commodity boards or monopolies.	Private monopolies nationalized or threatened; governments control commodity boards to focus research on smallholder farmers	Some nationalized monopolies broken up and privatized; liberalization allows new companies to enter; many commodity boards eliminated; government takes a larger role in funding and managing research	African and other foreign firms enter markets; more government firms privatized or closed; more technology from transfer and some R&D comes from new private owners and input companies

Source: Compiled by authors.

Growth of the Seed Industry

The seed industry in all of these countries went through a period of liberalization in the 1990s in combination with varying degrees of privatization, which has had a positive impact on R&D. In Kenya, no private maize cultivars were approved for sale before 1995, which meant that Kenya Agricultural Research Institute (KARI) had a de facto monopoly on research. The Kenya Seed Company (KSC), which produced seed from KARI's cultivars, had a monopoly on the distribution of certified maize seed until 1993. A key change allowing private companies to enter the market was a new willingness on the part of seed regulators to register cultivars from private companies. The government approved the first four private maize hybrids in 1996–2000 and the first two private sunflower cultivars in 1994. Monsanto entered the Kenyan market by buying Cargill's international seed business, and then registering its first maize hybrids in Kenya in 2000. Pannar registered its first sunflower and maize hybrids in 1994 and 1996, respectively. SeedCo's first maize hybrid was registered in 2003. In 2003–04, however, KSC still accounted for 86.5 percent of the total volume of maize seed produced by the formal seed industry in Kenya according to Ministry of Agriculture estimates (Odame, Kangai and Spielman 2011).

Private-sector plant breeding in Kenya has grown slowly. By 2000 Pioneer, Pannar, and Western Seed each reported having one breeder, and KSC reported employing 8,makinga total of 11 scientists outside of KARI (Ateka and Songa 2008).In 2008 Odame, Kangai, and Spielman 2011) reported 7.4 full-time equivalent (FTE) researchers in the four seed firms they interviewed. With the acceptance of private cultivars, farmers can now choose from over 100 hybrids and open-pollinated varieties from four

Kenyan companies, two companies from elsewhere in Africa, two U.S.–based multinationals, and KSC (Table 9).

Table 9.Maize cultivars registered in selected countries, 2000–09

Organization/location of headquarters	Kenya	Tanzania	Zambia
Private			
AFGRI Ltd, South Africa			3
Agri Seed, Kenya	8		
Faida Seeds Kenya	1		
Farm Inputs Care Centre, Uganda	1	3	
Kamano, Zambia			5
KIBO Seeds, Kenya		9	
Lagrotech, Kenya	2		
Monsanto, United States	7	4	6
MRI Seed, Zambia			16
Pannar, South Africa	15	8	36
Pioneer, United States	4	2	7
Progene, Zambia			3
SeedCo, Zimbabwe		5	20
Tanseed, Tanzania		3	
Western Seed Company, Kenya	29	3	
Zamseed, Zambia			9
Subtotal	*67*	*37*	*105*
Public			
Kenya Seed Company and Kenya Agricultural Research Institute	70 (31+39)	9	
Tanzania		10	
Zambia			8
Subtotal	*70*	*10*	*8*
Total (private and public)	**137**	**47**	**113**

Source: Government registered seed lists.
Note: KIBO Seeds is a subsidiary of the Kenya Seed Company and competes as a private company in Tanzania.

In Tanzania and Zambia the dominant role of the government seed companies, Zamseed and Tanseed, dissolved in the 1990s under financial pressures. Tanseed's sales collapsed as subsidies fell progressively from 70 percent in 1990/91 to 0 percent in 1994/95. Zamseed continued with donor support for some years, but by 2000 more than 50 percent of its ownership was private. While seed parastatals struggled and eventually left the field, other government policy changes, particularly the registration of private cultivars, allowed private companies to enter the market. In 1993, Cargill (active in Malawi) was the first private company to register a maize hybrid in Tanzania, followed by Pannar, Monsanto, and Pioneer later in the decade. In Zambia, Pioneer (with breeding in Zimbabwe) was the first company to register a maize hybrid in 1992; other private companies registering one or more maize hybrids in the 1990s include Carnia (at the time from South Africa), Cargill, Pannar, SeedCo, and the Maize Research Institute (MRI). In both countries the Africa-based multinational corporations Pannar and SeedCo have played a larger role than U.S.– and European-based multinational corporations (Table 9). In Zambia, the introduction of new hybrids has been taken over by Pannar, SeedCo, and local private companies, especially MRI. Zamseed has operated as a private company since 2000, with some breeding and favorable access to public cultivars. Tanzania has approved fewer private maize hybrids than Kenya and Zambia, but, more strikingly, almost all are from foreign companies; this may reflect Tanzania's low ranking on the ease of doing business index.

The partial openness of these markets has allowed national, regional, and other multinational seed companies to develop and introduce new cultivars, focusing on crops for which seed markets are large (especially in terms of hybrid maize) and for which the introduction of new cultivars is unregulated (vegetables and forage crops in Kenya and Zambia). Zimbabwe's SeedCo is a useful example. It began in 1940 as a private farmers' cooperative producing maize seed; in 1973 the cooperative purchased a breeding station, and in 1996 it was re-registered as a publicly owned company selling shares on the Harare stock exchange. It has developed into a regional multinational, expanding into Kenya, Zimbabwe, Malawi, Ethiopia, and other countries as their markets opened. As the business climate in Zimbabwe deteriorated, Seed Co moved some of its research to Zambia. The company also has a technology agreement with Syngenta that provides Seed Co with access to Syngenta's technology from elsewhere in the world, and Syngenta with access to SeedCo's white maize hybrids and soybean lines.

Recent (October 2011) interviews with large and small seed companies in Kenya, Tanzania, and the United States suggest continued growth in private technology introduction and R&D in Eastern and Southern Africa, responding not only to liberalization, but also to the technical opportunities presented by several new public–private research collaborations involving international research centers and national research programs. In East Africa small companies, such as Meru Agro-Tours in Tanzania, are starting hybrid seed production based on lines received from the Drought Tolerant Maize for Africa (DTMA) project. DTMA is a partnership of CIMMYT, IITA, government research institutes, and private seed companies in 13 countries in Africa. With some help from donors, these companies could eventually start their own breeding programs. Medium-sized companies in the region like Western Seed Company and Eastern Seed Company in Kenya get DTMA and CIMMYT lines from Mexico for their R&D program. Pannar and SeedCo also access CIMMYT lines from DTMA and from CIMMYT's Zimbabwe research program. The Bill and Melinda Gates Foundation's project on Water Efficient Maize for Africa (WEMA) has induced Monsanto to put 25 of its top scientists and technical staff to work with CIMMYT and national programs on developing drought-tolerant conventional and genetically modified maize hybrids for Uganda, Kenya, Tanzania, and Mozambique (personal communication with Kinyua M'Mbijjewe, Monsanto, Nairobi, October 25, 2011).

Senegal has a limited private seed industry. Private research is mainly conducted by one firm, Tropicasem, which breeds hybrid vegetables. It supplies vegetable seed throughout Western Africa from its base in Senegal. The company has not yet faced a truly competitive market due to very limited approvals of private cultivars from other companies; Tropicasem will likely face major changes when and if West Africa moves to regional variety lists, as has been agreed upon but not finally approved and implemented through the Economic Community of West Africa (ECOWAS) and the West African Economic and Monetary Union (UEMOA).

Policies and the Growth of the Plantation and Processing Industries

In the processing and plantations industries, government nationalization policies of the 1960s gave way to liberalization and privatization decades later (Table 8). The impact of nationalization and later liberalization on private technology transfer and research varies considerably among countries, products, and time periods.

Senegal privatized the companies that controlled the processing of two major cash crops, cotton and groundnuts, after 2000. The government sold 51 percent of SODEFITEX, the cotton monopoly, to a French company in 2003. Suneor, the government groundnut company, was privatized in 2005. Both of these companies have their own research programs. The third main cash crop, sugar, has been produced by a Swiss company since it was founded in 1971. It has conducted its own research on cultivars and crop management since it then, and added research laboratories in the mid-2000s. Privatizing large public-sector companies to private control has led to an initial increase in private R&D, but whether this is the best reform for long-term private innovation is not obvious. Limited competition increases profits, but experience from other industries and countries suggests that monopoly power reduces investments in innovation (Scherer 1980)

In Eastern Africa nationalization followed by liberalization and privatization has had mixed impacts on R&D in the plantation and processing subsectors. During colonial times, research on plantation crops, such as coffee and tea in Kenya and Tanzania; sugarcane in Kenya; and cash crops, such as cotton in Zambia, was originally financed by taxes (called cesses) raised by commodity boards to fund research institutes that they controlled. Independent governments nationalized some of the monopolies and extended government control over formerly autonomous research institutes. During the structural adjustment period of the 1980s and 1990s, governments privatized many parastatals and reformed commodity trade controls. Some new entry and competition was allowed in processing industries, such as cotton ginning in Zambia. The associated research activities were shifted to foundations or trusts controlled by the government, such that they essentially became government research institutes. These entities were sometimes targeting smallholder farmers, but with little direct involvement in management by private processors, estates, or smallholders. Some plantation companies started their own R&D programs. In Zambia, efforts to get cotton ginners to pay more and to force the Cotton Development Trust to be responsive to farmers' demands have been unsuccessful, and funding has been erratic (Tschirley, Poulton, and Labaste 2009). Byerlee (2011) points to similar funding problems for the Kenya Tea Research Foundation (KTRF). Representatives from Kenya's private tea industry reported that they had to increase their own research because the Foundation was not helping them solve their problems.

In Kenya in the 1970s monopolists controlled pineapple processing (Del Monte), barley (Kenya Breweries Ltd.), and tobacco (BAT Kenya Ltd.), paying for and managing research on these crops (Ndii and Byerlee 2004). Liberalization did not affect the pineapple monopoly, but SAB (the aforementioned South African Breweries) entered the beer industry in 1998, and a local company, Mastermind Tobacco, and another multinational, R. J. Reynolds, entered the tobacco industry. With the help of government seed regulators who prevented SAB from bringing in new barley varieties, Kenya Breweries was able to force SAB out in 2000 because it could not get access to barley produced from Kenya Breweries' proprietary barley varieties, and had to import barley with a 30 percent import duty. In this case, liberalization, which brought in a new brewery, created strong incentives to introduce new barley cultivars, but government controls blocked these potential innovations. Data on research expenditure were not available, so it is not known whether SAB's R&D increased or declined.

The one industry in Kenya in which research and innovation appears to have increased is the cut flower industry. It was established by a Danish firm in 1969 (Ndii and Byerlee 2004) and, with technology transfer and in-country R&D, has grown into a billion dollar industry led by three companies: Oserian Development Corporation, Karuturi, and Flamingo Holdings. Oserian has been conducting research at least since 1999 (Beintema, Murithi, and Mwangi 2003), developing new rose varieties and improved management practices, such as integrated pest management. Unfortunately, the company did not provide data on its recent R&D expenditure.

Privatizing government monopolies to multiple companies, as well as reforms allowing market entry to erode private monopolies, allows multiple companies to sell inputs, to bid for farmers' products, and to export raw and processed products. Such reforms may reduce the monopsonists' surplus and their incentive to do research and provide new technology. At the same time liberalization and privatization throughout the region has opened up new channels for introducing technology by increasing the number of firms competing, including agricultural input companies.

Policy Reforms, Innovation, and R&D in South Africa

Real R&D expenditures in South Africa doubled between 2001 and 2008, led by growth in the seed industry and SASRI sugarcane research institute."The most influencing policy initiatives in the participation of the private sector in South Africa's agricultural R&D have been the deregulation of the agricultural input and product markets and the liberalization of agricultural trade, which has increased the spill-in of agricultural technologies to South Africa" (Kirsten, Stander, and Haankuku 2011). Deregulation meant eliminating the commodity boards, which had controlled prices and inputs for most major field crops. These policies prompted new South African companies to engage input-related R&D, including the former farmers' coop AFGRI, and existing firms, such as Pannar, to increase investments in R&D. Policy changes in conjunction with the democratic elections and end of Apartheid led major agribusiness firms such as Pioneer and Monsanto to invest in South Africa.

Despite South Africa's policy changes, encouraging competition remains a concern in some inputs markets. Government regulators are actively engaged in keeping markets competitive. The fertilizer industry is dominated by Sasol, the South African energy giant. In 2009 it was forced to pay a 188 million Rand fine for colluding with two other companies to fix fertilizer prices paid by farmers (Seccombe 2009). In 2010, DuPont, which owns Pioneer Hi-Brid, tried to buy Pannar, but the South African government blocked the deal because it would have reduced the number of major maize seed suppliers from three to two, which could reduce farmers' technology choices and increase their seed prices. DuPont and Pannar appealed the decision, but their appeal was turned down in October 2011. It is not clear how these decisions will affect R&D and innovation in South Africa and other countries where both companies operate.

Trade liberalization and privatization in South Africa and the rest of Africa have encouraged South African firms to expand into regional markets, and foreign multinational corporations to use South Africa as abase for their operations elsewhere in Africa. This seems to be increasing technology transfer from South Africa to other countries in Africa, as well as technology transfer into and research in South Africa. A prime example of this phenomenon is Illovo Sugar, which is based in South Africa and has been 51-percent owned by Associate British Foods since 2006. In 2011 the firm spent US$3.5 million on research throughout Africa, up from $2.8 million in 2010 (Illovo Sugar 2011). It was a purely South African company depending on SASRI for its research until 1996, when it bought 50 percent of a Mozambique sugar mill. In 1997 it bought Lonrho Sugar Corporation, which had sugar assets in Malawi, Swaziland, Mauritius, and South Africa. In 1998 it bought the Tanzanian government's sugar company, and in 2001 it sold its Mauritius company and bought a Zambian sugar company that had been a parastatal. Illovo Sugar is now Africa's biggest sugar producer. In 2009/10, the estates it managed produced 6.1 million tons of cane, while independent growers supplied about 8 million tons of cane. About 40 percent of its production is in South Africa. Illovo Sugar accounts for 94 percent of sugar production in Zambia, 30 percent in South Africa, 35 percent in Swaziland, 46 percent in Tanzania, and 32 percent in Mozambique (Illovo Sugar 2011).

5. SUMMARY AND POLICY OPTIONS

Imported innovations in machinery, pesticides, fertilizers, poultry, and plant varieties have been very important to the development of modern agriculture in Africa. These technologies are now primarily brought in by private agricultural input industries and by some processing industries. Private-sector R&D is still quite limited in Sub-Saharan Africa with the exception of South Africa. It is concentrated in the maize seed industry and in the processing and plantation subsectors. There is also significant research in livestock inputs in Eastern and Southern Africa, fisheries and fish processing in Senegal, and cultivated forestry in South Africa.

Quantitative evidence on the impact of proprietary technology on smallholders in Africa is limited. There is evidence that adoption of proprietary hybrids of maize increased yields by almost 60 percent in Tanzania, and that poultry productivity in Nigeria increased when imported poultry stock and medicines were allowed. Another study shows large returns to sugarcane research in South Africa. Finally, many studies show that proprietary genetically modified maize and cotton can improve the yields, incomes, and health of smallholder farmers in South Africa and Burkina Faso.

The evidence presented above suggests that governments can encourage the introduction of more private technology by continuing to liberalize: allowing local and foreign firms to enter; providing firms with a stable policy and regulatory environment; strengthening IPR; and not taxing agriculture. When barriers to investment, importation, and the introduction of technology fall, private firms will introduce appropriate technology even to the smallest markets. Kenya illustrates partial liberalization. Although Kenya does not tax agriculture, has effective IPR, and has allowed competition in the maize seed industry, the Kenya Seed Company remains a government corporation, which limits private firms' share of the hybrid maize seed market and suppresses seed prices. Six of the seven sugar mills in Kenya are owned by the government. The parastatal Central Artificial Insemination Station (CAIS) has a de facto monopoly on the cattle semen market (sustained by regulations limiting who can extract semen, and what foreign bulls are approved). The Pyrethrum Board controls the pyrethrum supply chain.

Other factors that could increase markets and stimulate research are the reduction of barriers to regional trade in fertilizer, seed, and other agricultural inputs, and badly designed input subsidies that channel input trade through government tenders rather than markets. Further relaxation—or, as a second best, regional harmonization—of technical regulations on agriculture could have a big impact on the pace of cultivar introduction. Many of the surveyed companies commented on this.

Biosafety regulations that allow the use of safe genetically modified organisms could induce research in some countries. In the case of the seed industry, one of the major stimulants to research in India, Pakistan, and South Africa has been the introduction of genetically modified technology. In the study countries, genetically modified plants are only permitted for use by farmers in South Africa**.**

Public research to overcome market failure to produce enough public and quasi-public goods can stimulate R&D and the introduction of private technology. Shortages of well-trained scientists are a major constraint to the growth of private R&D in all countries in Africa (even South Africa). In SSA, this is a constraint not only on research, but also on the technology regulatory system and on science policies. Thus, continued expansion of higher education and PhD training is necessary.

Public–private partnerships, such as DTMA and WEMA could stimulate innovation and R&D by small and medium-sized maize seed firms in Africa and encourage multinational corporations like Monsanto to focus more research efforts on Africa.

African government and donors could do more to encourage South–South technology transfer. China and India are already large suppliers of generic pesticides and agricultural machinery. Vegetable seeds from Indian companies are sold throughout Africa. Chinese and Indian seed companies are just beginning to explore the possibilities of entering Africa markets for hybrid seeds of field crops, such as rice (from China) and maize, millet, and sorghum (from India).Technology can come from many other countries at similar latitudes, such as Bangladesh, Brazil, Mexico, and Thailand. Programs to encourage South–South contacts could have major payoffs.

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sustainable solutions for ending hunger and poverty
Supported by the CGIAR

2033 K Street, NW | Washington, DC 20006-1002 USA
Tel: +1.202.862.5600 | Skype: ifprihomeoffice
Fax: +1.202.467.4439 | Email: ifpri@cgiar.org
www.ifpri.org

FORUM FOR AGRICULTURAL RESEARCH IN AFRICA

PMB CT 173 | Accra, Ghana
Tel: +233.302.772823
Fax: +233.302.773676 | Email: info@fara-africa.org
www.fara-africa.org

The Agricultural Science and Technology Indicators (ASTI) initiative compiles, analyzes, and publishes data on levels and trends in agricultural R&D investments, capacities, and institutional arrangements in developing countries. ASTI is managed by the International Food Policy Research Institute (IFPRI) and involves collaborative alliances with many national and regional R&D agencies.

Jointly convened by ASTI/IFPRI and the Forum for Agricultural Research in Africa (FARA), the conference, "Agricultural R&D—Investing in Africa's Future: Analyzing Trends, Challenges, and Opportunities," brought together experts and stakeholders from the region to contribute their expertise for the purpose of distilling new insights and creating synergies to expand the current knowledge base. The themes under focus were (1) why African governments under invest in agricultural R&D; (2) how human resource capacity in agricultural R&D can be developed and sustained; (3) how institutional structures can be aligned and rationalized to support agricultural R&D; and (4) how the effectiveness of agricultural R&D systems can be measured and improved.

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